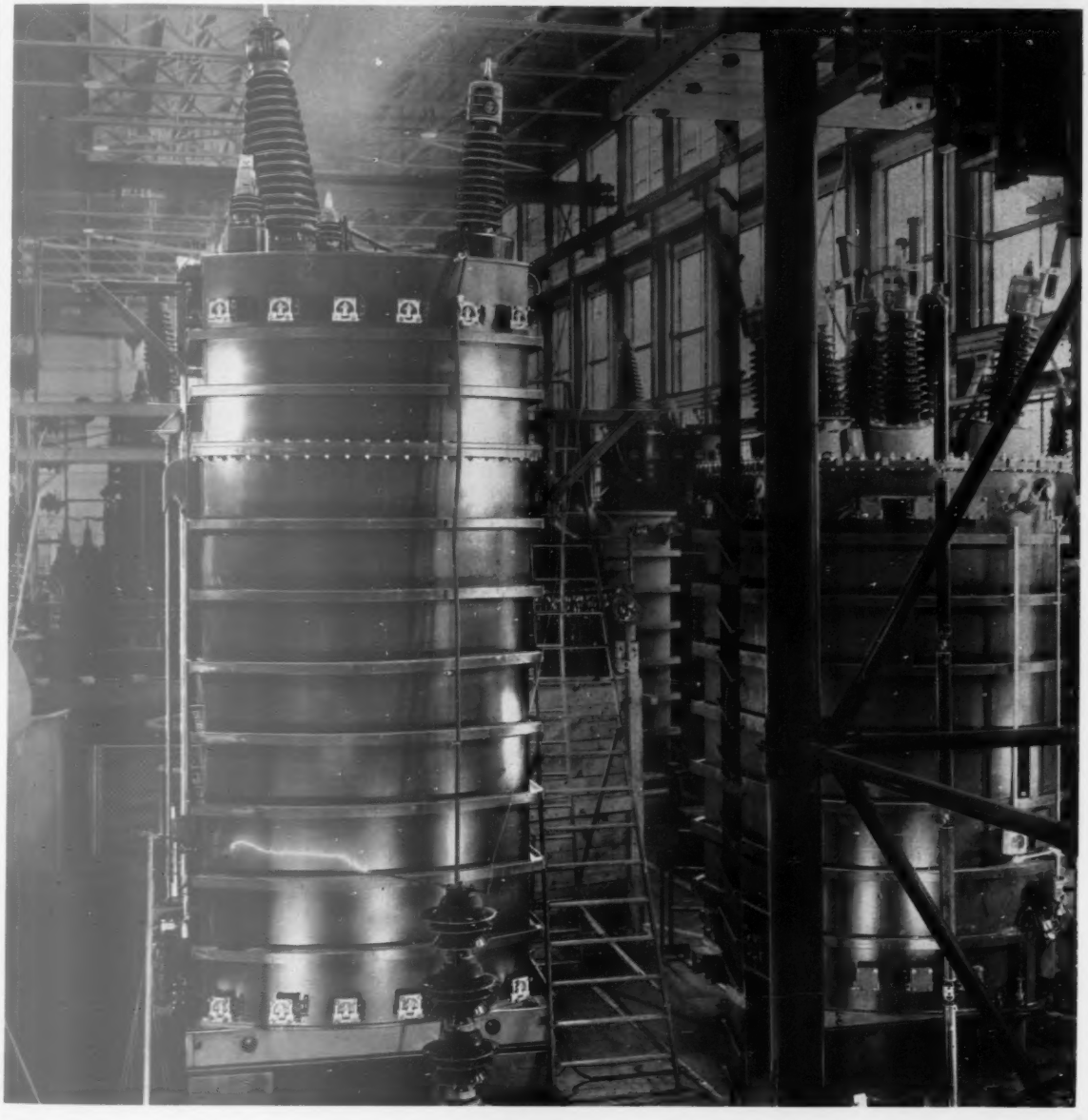
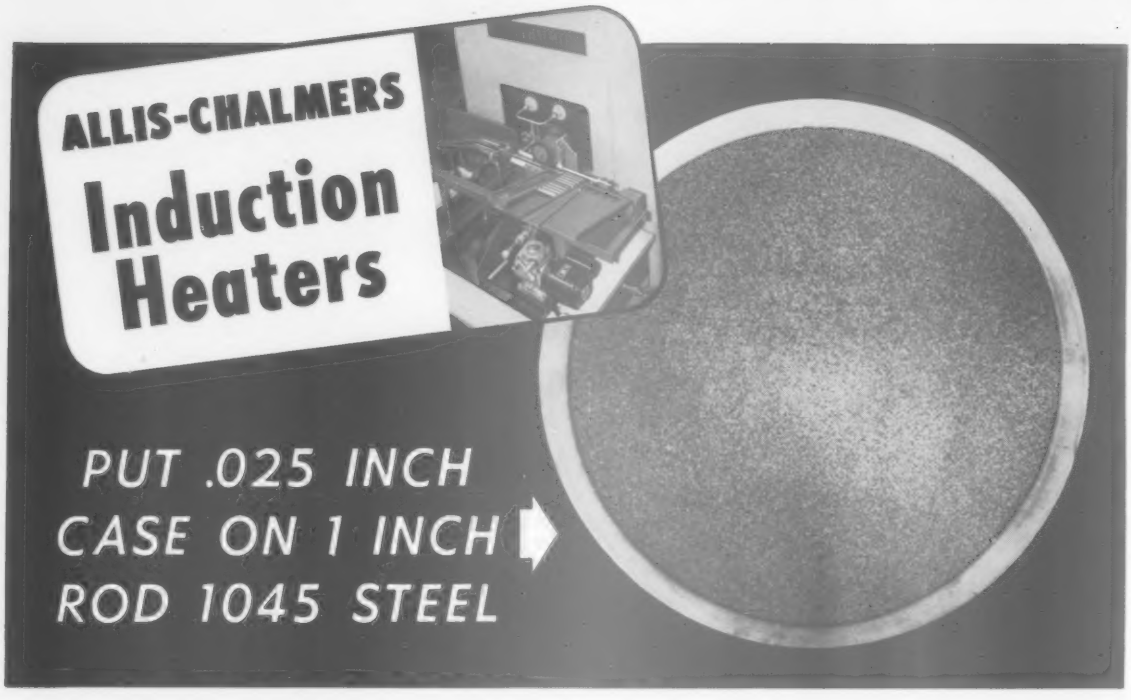
ALLIS-CHALMERS

Electrical Review



Fourth Quarter, 1950



RATE: 1.36 seconds per inch
COST: 37/100¢ per inch

THIS IS TYPICAL of what Allis-Chalmers Induction Heaters can do to speed up production. On job after job, these units do hardening, annealing, soldering, brazing, and heating cheaper, faster, better!

Cheaper — because so many more parts can be processed in an hour.

Faster — because induction heating takes only seconds.

Better — because product quality is improved by close heat control.

In addition, the Allis-Chalmers Induction Heater is versatile. By simply changing the work coil, the same heater can braze, solder, anneal, case, and through-harden . . . no need for additional output transformers (needed on most units) which require special shielding and skilled help to install.

Not only is the cost low per part processed, but the cost of owning and operating an Allis-Chalmers Induction Heater is surprisingly low too.

COST PER HOUR
to own and operate an Allis-Chalmers Induction Heater

	10 kw unit	20 kw unit
Tube replacement (5,000 hrs.)	0.070	0.110
Fixed energy	.020	.034
Load energy 50% cycle	.140	.200
Water	.010	.032
Amortization 20,000 hrs.	.244	.354
Total cost	$0.484	$0.730

Find out what Allis-Chalmers Induction Heaters can do to lower costs in your plant. Call your nearby A-C Sales Office.

Send Coupon Now!

Allis-Chalmers, 848-A S. 70th St.
Milwaukee, Wisconsin

Please send me Induction Heater booklet 6430A.

Name _____

Title _____

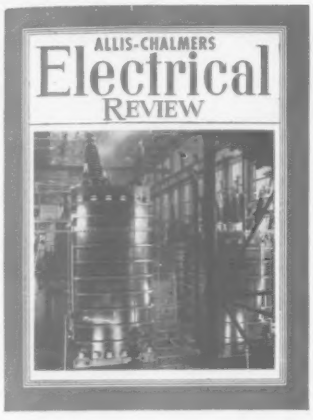
Company _____

Street _____

City _____ State _____

A-3203

ALLIS-CHALMERS



CHOPPED WAVE TEST being applied at 1035 kv is one of several tests used to determine structural and operating characteristics of transformers before they are installed. Unit shown is one of a bank of three 110-kv—220-kv, 35,000-kva autotransformers for a West Coast electrification project.

Modern high voltage impulse testing facilities like this have reduced impulse testing time considerably. Details about the modern test floor layout and equipment used and the fault-detection procedures are described in articles in this issue appearing on pages 10 and 13, respectively.

Allis-Chalmers Staff Photo

★

Allis-Chalmers

Electrical Review

Vol. XV No. 4

Executive Board
R. M. Casper F. W. Bush
A. R. Tofte

Editor...G. C. Quinn

Managing Editor.....J. Vitercik
Assistant Editor...R. W. Smeaton
Technical Editor...W. L. Peterson

Associate Editors: P. Castner, D. Dalasta, J. A. Zimmerman, O. Keller, M. C. Maloney, T. B. Montgomery, W. Richter, R. Serota, D. Journeaux, H. J. Baerwald, B. A. Storaasli, P. L. Taylor.
Circulation: John Gumtz.

Issued quarterly. Subscription rates: U. S., Mexico, and Canada, $2.00 per year; other countries, $3.00 in advance.

Address Allis-Chalmers Electrical Review, Milwaukee 1, Wisconsin.

Printed in U. S. A.
Copyright 1950 by
Allis-Chalmers Mfg. Co.

ALLIS-CHALMERS Electrical REVIEW

★

Contents

New Trends in Turbo-Generators..... 4
L. T. ROSENBERG

Impulse Testing Without Delay..... 10
J. H. MORAN

Corona — Another Transformer "Has-Been"..... 13
L. C. AICHER

Patents Make Sense, IF —..... 20
J. S. LIEB

Repainting Transformers in the Field..... 26
J. R. MANN and O. V. STEWART

The Betatron Today — Part Two of Two Parts..... 29
R. C. ODELL

★

Indexed regularly by Engineering Index, Inc.
Allis-Chalmers ELECTRICAL REVIEW is available to public and institutional libraries on microfilm from University Microfilms, 313 N. First St., Ann Arbor, Mich.

NEW Trends in Turbo Generators

by L. T. ROSENBERG
Motor and Generator Section
Allis-Chalmers Mfg. Co.

Improved design and standardization have fostered greater reliability, accessibility, and more favorable operating characteristics.

BECAUSE OF THE REQUIREMENT of exceptional dependability the development of large power equipment is inherently a slow-moving, cautious process. Traditionally, both the manufacturer and the user have shown a reluctance to accept abrupt changes before they have proved themselves in service.

And so it has been with the turbo-generator. Improvements in design are normally made with extreme caution, and even then only in response to a definite need. Recently, however, a number of changes have taken place within a relatively short period that have somewhat accelerated this gradual evolution.

The phenomenal increase in the ratings of 3600-rpm turbine-generators and the consequent problems arising in their design and operation have been one of the compelling influences in the adoption of new features of construction. Similarly, the AIEE-ASME standardization program, departing somewhat from earlier practice in both short circuit ratio and power factor, has perhaps for the first time offered the industry a golden opportunity to incorporate sweeping improvements in a large group of ratings.

By concentrating on the standard ratings, more engineering and design time has been available for improvements in appearance, cooling, insulation, accessibility, and performance. Let us consider these inter-related factors and how modern turbo-generator design has brought about improvement in each.

Appearance begins with good yoke design

Utilities have been quick to realize that the power plant with streamlined, quiet running units can be a beautiful show place and serve as a means of furthering consumer good will. A smooth cylindrical stator yoke is naturally pleasing to the eye. Structurally, some means of support from the foundation is necessary and provision must be made for inclusion of the heat exchangers within the housing and for the water connections to them. Figure 1 shows typical recent designs in which these requirements are met while preserving the streamlined appearance.

Two types of yoke construction are shown. Both maintain the concentric cylindrical form and lend themselves well to the use of aprons, see Figure 2, concealing the supporting feet and piping, and adding materially to the overall appearance. In the four-cooler style the water piping enters the sides of the yoke, the connections to the coolers being made from behind the stationary heads as the coolers are slid into place on steel rails. Neither type requires disturbance of the piping, nor shutting the unit down while coolers are opened up for cleaning. The latter feature results from patented gasket seals between the tube sheets and the yoke end plates which are not disturbed when the water box covers are removed.

Rigid yokes replaced by flexible construction

In two pole generators, the magnetic pull across the air gap is considerably greater in the direct pole axis than that crosswise to the poles. The stator punchings are therefore distorted slightly into an elliptical form when excitation is applied, the distortion rotating with the rotor. In small machines

STATOR YOKES for hydrogen-cooled generators shown above illustrate the fact that modern stators have provision for two or four longitudinal coolers, depending upon the size of the machine. **(FIGURE 1)**

THIS 20,000-KW standard hydrogen-cooled generator has the 75-kw main and 3½-kw pilot exciters in the front housing. The apron and lagging soften sharp corners and conceal lifting lugs and piping. **(FIGURE 2)**

this effect was negligible, but as generators grew in size considerable rigidity had to be built into the yoke to prevent the transmission of noise and vibration to the surrounding room and foundations. Machines were built up to 62,500 kva at 3600 rpm with yokes adequate in strength and rigidity to prevent objectionable noise or vibration. Some of these units have been in service 10 to 12 years, and all are giving highly satisfactory performance.

These large rigid yokes were not well suited to the new streamlining, however, and in some cases generators have towered higher than the steam turbine. Moreover, they were difficult to ship completely wound. Consequently after thoroughly studying various methods of flexibly supporting the stator punchings, the ingenious construction shown in Figure 3 was evolved.

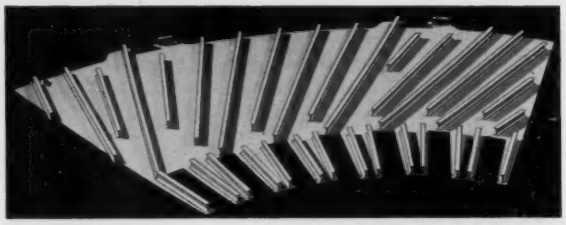
The inner steel cylinder, which carries the punchings and windings, is supported only at its extreme ends, there being no other rigid connection to the outer shell or feet. The flexible member is then the portion of the inner cylinder extending from the core to the end plates at both ends. Elasticity for the natural elliptical distortion is obtained without sacrificing adequate strength to resist either transverse or torsional forces due to sudden short circuits.

Actual tests on 10-, 15-, 20-, 30-, and 40-megawatt units have shown this simple, rugged construction to be extremely effective with magnetic forces ranging up to 170 percent of normal. The application of field to one of these machines can scarcely be detected, even at close range.

Stator ventilation keeps apace

As high speed machines began to grow in size, maximum diameters were soon reached. Further increase in ratings meant longer units. It was recognized many years ago that stator ventilation through the air gap alone was inadequate. In 1924, application was filed for a patent covering the "Multiple Radial" principle of stator ventilation in which the cooling medium entered the core and windings from the outer periphery at several points around the circle. Guided by specially shaped I-beam spacers, the gas, after flowing into the core, returned to the outer periphery at the intermediate positions between the inlet points, and from there found its way into the discharge. With sufficiently large fans and axial ducts, the stators of generators of any desired length could be properly ventilated.

This outstanding improvement was widely accepted and served well for 13 years. But it had two important points of possible improvement. In the first place, a large share of the air was by-passed through the core alone, leaving a relatively



SPACER SEGMENT for spiral ventilation shows how the I-beams, spot-welded to the punchings, form the stator vent ducts. **(FIGURE 4)**

minor quantity for passage down through the teeth and coils. In addition, the groups of coils located in the incoming cool air were several degrees cooler than those in the path of the somewhat warmer discharging air. In the meantime, methods of rotor ventilation had overtaken the advances in stator cooling, so some further improvement was desirable.

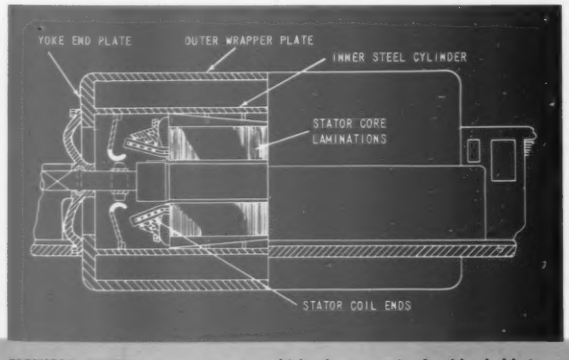
After carefully studying and testing a number of suggested schemes, a 7500-kw spirally ventilated stator was designed and built in 1937, overcoming both of the objections of the previous patent. The test results were so satisfactory that the new principle was adopted at once.

To accomplish the uniform, effective cooling of spiral ventilation, the I-beam spacers are spot welded to the punching as shown in Figure 4. The partially stacked stator of Figure 5 shows a complete circle of these vent segments as they are installed. The cool air (or hydrogen) flows into the stator from both ends along the six (highlighted) ducts and feeds into the core from the outer periphery. It is then guided spirally inward to cool alternate groups of stator coils. Upon entering the air gap, the already partially heated gas absorbs more heat from the rotor before finally passing radially outward through the intermediate groups of stator coils. To avoid the uneven temperatures between the alternate groups, the direction of the spiral is reversed in each successive duct along the core length. All coils are thus alternately cooled by incoming and outgoing gas every inch or two along their length.

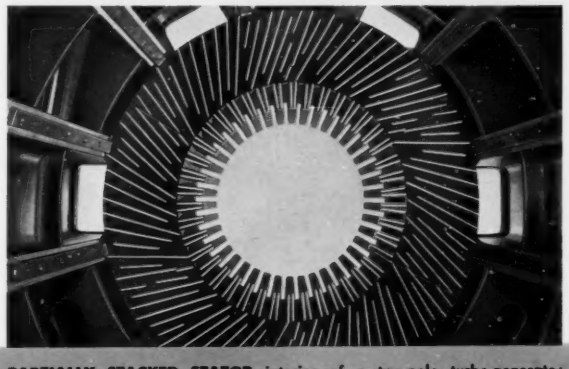
An interesting study and series of experiments were undertaken recently to determine the optimum spacing of the stator ventilating ducts. It is shown in the appendix that, with a fixed core loss and duct wall temperature, the center of each iron packet will rise above the duct wall by an amount:

$$\theta_o = \frac{q''' s^2}{2k_x} \text{ °F} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where: $q''' =$ Internally generated heat (core loss) in btu/hr/cu. ft.



FLEXIBLE YOKE construction in which the core is flexibly held in a tube-like inner shell is more adaptable to today's streamlined design than the large and cumbersome rigid yokes of the past. **(FIGURE 3)**



PARTIALLY STACKED STATOR interior of a two-pole turbo-generator shows how punchings are stacked in the stator on non-magnetic dovetails securely bolted and doweled to the flexible inner shell. **(FIGURE 5)**

s = One half the packet thickness in feet.

k_x = Coefficient of heat transmission crosswise of the laminations.

This relation shows that the temperature rise of the interior of the packet above that of the duct wall will be proportional to the square of the packet thickness. Using an experimentally determined coefficient of heat transfer, a good grade of steel operating at a flux density of 100,000 lines per square inch can be shown to rise 19 degrees C at the center of a two-inch packet but only 4.7 degrees C in a one-inch packet of laminations.

This means that the 1½ to 2-inch packets that were accepted for many years were not giving the most effective cooling. Experiments have borne out the superiority of the closer spacing of the ducts, and present practice is not to exceed a 1¼-inch packet thickness whenever possible.

To keep the core loss (q''' in equation 6) low, modern practice is to use only the finest grade of thin, low loss, non-aging, high silicon steel in the core. Before being punched, each lot of steel is tested for permeability, core loss and ductility. The entire segmental lamination is punched in a single operation to insure accurate alignment when stacked. The punchings are then rolled, annealed, and coated on both sides with an oil-proof, moisture-proof, baked-on insulating enamel. Operation of hydrogen-cooled generators in air for a period to cure the core varnish has not been found necessary.

It has been well known for years that the extreme ends of the stator teeth are vulnerable to overheating, due to leakage flux, particularly when operating at leading power factor. Some designs have used either stepped or tapered core ends to prevent excessive temperatures. One method has employed non-magnetic core clamping plates and non-magnetic rotor coil retaining rings for this purpose. An important further advance in coping with core end heating was recently developed. It consists of one or more narrow radial slots punched in each stator tooth extending one or two packets deep from end of the core. Tests on both air and hydrogen cooled machines have been very gratifying. In one case a reduction of 43 degrees C in tooth end temperature was achieved with the radial slots.

Considerable progress in the testing of stator cores occurred within the past two or three years. The test consists of wrapping several turns of cable through the core and yoke and exciting at normal frequency with sufficient current to produce normal flux density in the core. With the rotor removed, complete access to the interior is possible for detecting abnormal temperatures due to shorted punchings. The core loss as well as the magnetizing current can also be checked to be sure the core is normal. As the test can be applied either before or after the coils are installed, it is also useful for checking the condition of old cores and to determine the effectiveness of temporary core repairs after a slot failure in an old machine. By the use of this test it was learned, among other things, that a new broaching process for conditioning the slot walls prior to winding is safer than the tedious filing procedure formerly employed.

Stator coil insulation makes good record

The stator coils of a modern turbo-generator are form wound, interchangeable, and — when possible — made in halves for ready assembly or repair. The conductor is subdivided into many thin, insulated strands, suitably transposed to minimize eddy current losses. Class B insulation is used on all turbo-generators above 5000 kw. It is applied in the form of a liberal number of layers of mica tape, thoroughly impregnated and bonded together with high grade asphaltum-base insulating compound. The insulation is vacuum treated and the slot portion is hot moulded to exact size, in several stages, under pressure in steam-heated dies. The result is a well bonded, compact insulating wall, free from pockets or moisture, insuring good thermal conductivity as well as a high dielectric strength.

The outer protective coil armor of heavy asbestos tape is impregnated with a semi-conducting varnish throughout the slot part of the coil and slightly beyond at each end to eliminate corona action.

The insulating procedure outlined above has proven itself by years of satisfactory service. Cases of tape migration or other defects have been exceedingly rare if not entirely non-existent. The materials used are sufficiently pliable to permit safe installation either in half coils or whole coils, and heat transfer has presented no problem whatever.

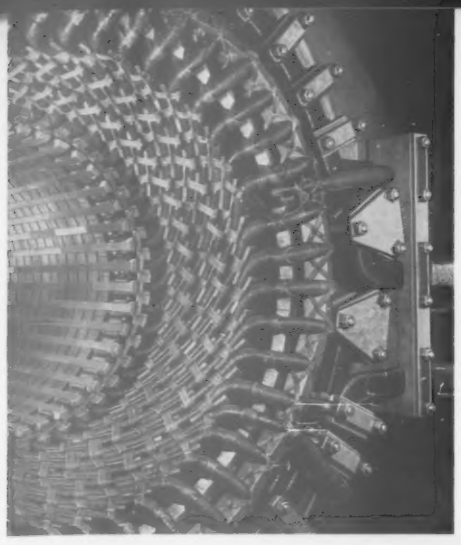
The stator coil ends are securely lashed to non-magnetic metal brackets, rigidly bolted to the stator clamping plates. Figure 6 shows the manner of bracing the stator coils of a two-pole, 3600-rpm generator built for switchgear and fuse-testing service. Although the unit shown is subjected to 16 times the short circuit forces of a normal generator, and must withstand these shocks repeatedly many times a day, the coil end supports are nevertheless the same in principle as those of standard turbo-generators. Inspection of the unit after two years of operation indicated only minor servicing required at a few points where the cording had loosened.

In large generators, unless the voltage rating is raised appreciably above the usual 14,400 volts, the current rating per terminal may become enormous. Aside from the difficulty of obtaining bushings rated in excess of 6000 amperes, the high current would cause considerable local heating in the generator shell if ordinary steel were used around the bushings. Modern practice has been to weld a plate of non-magnetic steel, large enough to include all the bushings, into the bottom of the shell. Where single bushings are inadequate to handle the current, two bushings per terminal are used.

Improved accessibility reduces inspection time

Because of the huge investment involved in a power plant, the great loss resulting from a prolonged outage is well recognized. Recent years have seen an attempt to minimize this outage time of turbo-generators by incorporating a number of features that facilitate inspection and maintenance. Inspection covers are provided at both ends, large enough to permit entry into the generator housing without disturbing the end covers or hydrogen seals. The inner covers are made of aluminum alloy in light, easily removable sectors, exposing the ends of the stator coils and rotor for examination.

Should rotor removal be desired, the outer covers are in halves, each half sliding vertically without disturbing the generator coolers. As stated before, cleaning of the coolers does not require taking the unit out of service. The construction of the generator bearings permits removal of the main bearing caps without disturbing the hydrogen seals. Servicing and maintenance of the hydrogen equipment is reduced to a minimum because of the greatly simplified hydrogen control system made possible by the thrust-bearing type of hydrogen seal developed in the late 1930's.



STATOR COIL BRACING of this 3600-rpm fuse and circuit breaker test generator for short circuit duty is similar to bracing of standard turbo-generators. **(FIGURE 6)**

ROTOR VENTILATING SLOTS being machined into the rotor of an 80,000-kw hydrogen-cooled generator must be narrow and deep to carry the cooling medium to where it will do the most good. **(FIGURE 7)**

Hydrogen auxiliaries no problem

Details of the simplified hydrogen control, used on machines of all sizes, have been fully covered elsewhere.[1] Briefly stated, the extremely close (oil film thickness) contact possible with the thrust type seal permits only a minute quantity of the seal oil to enter the hydrogen atmosphere; in some cases as little as three gallons per hour for both seals. This means the quantity of air or moisture brought into the generator by the oil is likewise small. As a result, vacuum treatment of the oil, or drying of the hydrogen, has not been found necessary, even though some of the early hydrogen-cooled units were supplied with facilities for vacuum treatment and drying. Thus, the seal oil is now taken directly from the turbine oil supply.

The hydrogen instruments are also greatly simplified, consisting essentially of an inclined U-tube for measuring hydrogen purity and a mercury U-tube for gas pressure. If desired these instruments can be mounted directly on the side of the generator, requiring no other panel. For use during scavenging, a secondary mercury U-tube showing gas pressure can be hung at the lower end of the filling pipe adjacent to the hydrogen and CO_2 manifolds. A gas temperature indicator and the alarm lights can also be mounted on the machine with the two pressure gauges. Operation is fully automatic, and the alarms include only:

Hydrogen pressure — low.
Seal oil pressure — low.
Presence of liquid.
Emergency seal oil pump in operation.
Failure of power supply to alarm circuit.

The small amount of seal oil issuing from the hydrogen atmosphere flows through a sight flow gauge down into a detraining tank of large enough section to permit most hydrogen bubbles larger than 0.001 of an inch to rise and return to the generator via the oil drain pipe, which is made large for this purpose. The earliest designs of detraining tanks included an atmospheric vent connection to permit continuous or intermittent scavenging from the region of the seals. This feature, of course, was not found necessary. To avoid mounting the detraining tank where it might interfere with foundations or other equipment, it can be welded to the bottom of the generator shell. Several large units are already in operation with such integral detraining tanks.

Better rotors for two-pole units

The rotors of modern large turbo-generators are forged in one piece from a nickel-vanadium or nickel-molybdenum alloy steel ingot. They are bored throughout their length for periscope inspection. Although ultrasonic inspection methods are being studied, they are not being relied upon entirely up to the present. Figure 7 shows a large rotor forging in the process of having its ventilating ducts machined. The axial vent slots in the teeth and poles of turbo rotors were employed as early as 1935 on a 12,500-kw generator. Exceptionally favorable results were obtained because of the proximity of the ducts to the slot wall and the fact that the ducts occupy relatively cheap space where flux densities are low. Moreover, the rotor I^2R loss was transferred to the cooling medium without having to pass through the bottleneck at the rotor surface where pole face losses are also being transmitted.

To control rotor surface losses arising either from the tufting of flux or from the stator mmf harmonics, and to aid in the dissipation of heat, fine circumferential surface grooving to an appreciable depth has been found beneficial. Turbo-rotors above 5000 kw as well as many smaller ratings utilize both the axial vent slots and the surface grooving.

Rotor coil design has remained much the same for many years. The coils are of specially alloyed strap copper, wound on edge, designed adequate in width to give a mechanically stable coil shape that will not collapse easily under centrifugal force. As a result, there have been no rotor failures due to progressive deformation or thermal cycling.

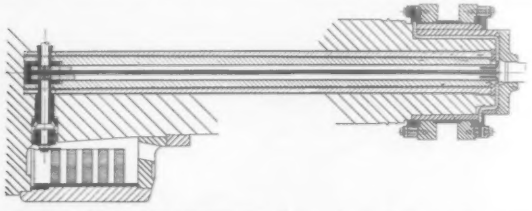
The rotor slot insulation consists of a one-piece, hot-moulded mica and asbestos slot channel extending well beyond the core ends. To improve the heat transfer, an outer wrapper of steel is also moulded to the channel. The coils are inserted turn by turn, with a heavy strip of finest quality mica plate forming the turn insulation. In large rotors, an inverted channel or cap is placed over the top of the coils. Rotor slot wedges are of non-magnetic steel specially shaped to minimize stress concentration.

Rotor coil ends are securely blocked with bakelized asbestos blocking after the rotor has been run up to a substantial speed to insure settling of the coils into their natural position. Taping of the coil ends with asbestos or glass tape is employed on modern hydrogen-cooled rotors merely to wrap the channel ends and hold the blocking in place.

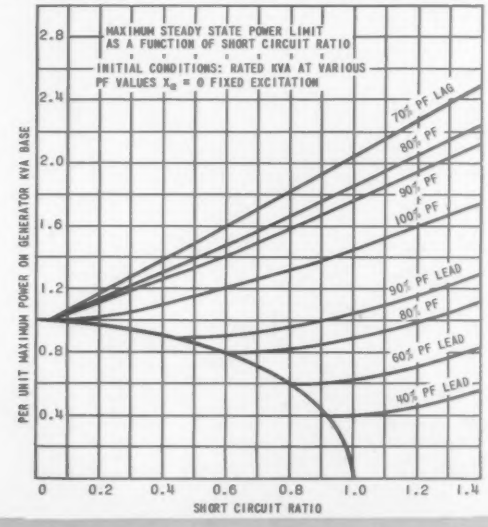
Figure 8 illustrates the hydrogen tight collector lead arrangement patented in 1940. The studs are sealed by means of lead washers and are taper-threaded into bushings brazed to the copper collector leads, the threaded contacts being silver plated. The centrifugal force of the stud is not carried by the contact threads. A generously proportioned steel nut, insulated from the stud as shown, is threaded into the rotor forging to carry the radial force. The two collector lead bus bars are mica insulated and assembled outside the rotor, together with the flexible straps forming the connections to the collector rings. They are then slipped into the bore as a unit.

To insure a good electrical as well as thermal contact with the helically grooved steel collector rings, auxiliary brass rings are securely bolted to the steel rings. This feature was developed as early as 1926. Its use has been so effective that, even today, with the extremely high field currents and collector ring speeds of the large generators, no need for higher excitation voltage than 250 volts has thus far been encountered in slip-ring construction.

The rotor coil retaining rings are forged in one piece from an ingot of non-magnetic alloy steel, high in manganese, nickel, and chromium. Manufacturing techniques have produced physical properties more than adequate for the largest 3600-rpm rotors. Retaining rings on turbo-generators are shrunk over the rotor body as well as over the end disc, which is in turn shrunk over the shaft and held in place by a key and spanner nut. Danger of local heating at the ends of the rotor wedges due to single-phase operation is minimized by providing a machined contact of large area between wedge and retaining ring, held firmly together by centrifugal force on the wedge end. The support for the mica-insulated rotor coil ends is completely rigid, eliminating the possibility of movement or vibration and their consequent ill effects on the mica.



COLLECTOR LEAD ARRANGEMENT shown above illustrates the manner in which the connections are carried to the rings. For best results, leads are insulated with mica and securely held in place. **(FIGURE 8)**



STEADY STATE power limit curves show that, on large systems, 0.8 short circuit ratio or even less does not seriously curtail leading power factor loads. **(FIGURE 9)**

Leading pf loads pose stability problems

The tendency toward reduced short circuit ratio as manifested in the AIEE-ASME standard line and in proposed NEMA standards for the most part has been viewed with apprehension by electrical system engineers. The widespread use of static capacitors often results in under-excited generator operation during light loads. A glance at the family of curves of Figure 9 shows, in a general way, the influence of short circuit ratio upon the steady state stability limit at various operating power factors. Considering that under-excited loads are generally well below full load in kw, the curves offer some reassurance at least for the case of zero external reactance.

In the event of system faults, or when other equipment is tripped off the system, the resulting sudden load swings require high transient stability. In general, a low transient reactance and a high moment of inertia are helpful. For a given nameplate rating, the large, heavy generator design will inherently possess these qualities. From the standpoint of fault currents, circuit breaker ratings, neutral grounding devices, and mechanical forces, high subtransient and zero sequence reactances are desirable. The latter can be increased appreciably by avoiding stator coil pitch values in the neighborhood of ⅔.

The long pitch coil, well above ⅔, is to be favored and is used wherever possible for various reasons. Foremost among these is the fact that it suppresses the harmful fifth and seventh harmonics of mmf together with their resulting stray losses and increased rotor heating. The triple frequency voltage harmonics (for the suppression of which the ⅔ pitch is ideal) can also be controlled by the correct arrangement of the rotor slots. Besides, ⅔ pitch in general is less beneficial in reducing the non-triples than any other short pitch. In any case, with proper system design and coordination, the triple harmonics no longer constitute a serious problem, except perhaps the nuisance of circulating ground currents where two neutrals are grounded.

As pointed out in a previous paper[2], a substantial skew of the stator slots will reduce all harmonics, particularly the higher frequencies most objectionable in cases of telephone noise. A full slot pitch of skew will virtually eliminate the slot ripple, and for this reason many large turbo-generators are being built today with a skew of one slot pitch. The necessarily more complicated drawings and tools and the increased manufacturing time are costly, but these sacrifices are believed justifiable in order to build a better machine.

Trends in exciter development

As indicated above, excitation voltages higher than 250 volts do not yet appear imperative in view of adequate collector ring design. While true that for a given speed a larger exciter

"WALK-IN" EXCITER HOUSING consisting of a one-piece, spacious steel enclosure protects exciters and collector rings, yet affords perfect accessibility for inspection. **(FIGURE 10)**

can be built at 375 volts than at 250 volts, the greater number of generator rotor turns will result in higher induced voltages when the field current is interrupted, adding to the hazard to operating personnel while servicing brushes. Moreover, the wide rotor conductor employed for the mechanically stable coil shape is inherently thin, even at 250 volts, and permits good space utilization in the rotor slots with the sensitive control of the desired full-load excitation voltage.

So far as the present rotor insulation is concerned, excitation voltages of 375 or even 500 volts are not prohibitive.

Exciter ratings up to 150 kw, at 250 volts, are being built at 3600 rpm without the objectionable shrink ring over the commutator. Above 150 kw at 250 volts the geared 1800-rpm exciter is used. Some utilities prefer geared exciters for even the smaller ratings, and so of course these are available.

Figure 10 shows a modern "walk-in" exciter and collector ring enclosure. Providing all the advantages of completely enclosing main and pilot exciters, and generator collector rings, it affords the ultimate in accessibility to the operator for inspection or changing brushes. It has been applied to turbine units from 10,000 kw up, and can be arranged either for recirculation or for room or basement ventilation through filters. Figure 11 shows how the enclosure harmonizes with overall unit appearance, and Figure 12 illustrates its suitability for outdoor machines, the doors and windows being water tight.

Because of the growing tendency toward under-excited operation in many plants, attention has recently been focused on automatic voltage control of large units for which only manual control was heretofore believed sufficiently reliable. Great strides in reliability and effectiveness of regulators have been made within the past two years in the form of the rotating regulator known as the *Regulex* exciter. It consists of a rotating dc machine, having no moving or wearing parts or contacts other than the rotating member, controlled entirely by a static network, and having the reliability associated with an ordinary transformer.

The *Regulex* exciter equipment takes the place of the conventional pilot exciter. In conjunction with its network, it operates on the main exciter to raise or lower the main alternator excitation quickly as required. In addition to the usual functions of voltage and kvar control, it can also be arranged to prevent automatically generator excitation from being reduced below a safe value for the particular kw load being carried at the time. This type of protection is finding acceptance in central stations throughout the country.

APPENDIX

The general equation for the flow of heat within a solid can be derived by writing the heat balance relation for an elemental cube of the material. If internally generated heat is present, the resulting expression, sometimes known as the Fourier-Biot equation, is:

$$\rho C_p \frac{\delta t}{\delta \tau} = k_x \frac{\delta^2 t}{\delta x^2} + k_y \frac{\delta^2 t}{\delta y^2} + k_z \frac{\delta^2 t}{\delta z^2} + q''' \qquad (1)$$

where: ρ = the density of the material.

C_p = the specific heat of the material.

t = temperature

τ = time

x, y, and z are distances measured in the three directions.

k_x, k_y, and k_z are coefficients of heat transmission in the three directions.

q''' = internally generated heat in btu per hour per cubic ft.

Equation (1) is greatly simplified when applied to the steady state case of the single packet of stator core iron of Figure 13, since the left hand member is zero for steady state conditions. Moreover, if the y and z dimensions are large compared to the packet thickness, heat flow in only the x direction need be considered. The remaining relation becomes:

$$\frac{d^2 t}{dx^2} + \frac{q'''}{k_x} = 0 \qquad (2)$$

If the total temperature, t, is made up of the duct wall temperature, t_s, plus the internal rise, θ, then $t = t_s + \theta$, and for a fixed duct wall temperature, t_s: $\frac{d^2 t}{dx^2} = \frac{d^2 \theta}{dx^2}$ (3)

Hence, the equation for steady, crosswise heat flow in the packet is:

$$\frac{d^2 \theta}{dx^2} + \frac{q'''}{k_x} = 0 \qquad (4)$$

Integrating twice and solving for the constants of integration from the known boundary conditions, we get the temperature distribution through the packet:

$$\theta = \theta_o - \frac{q''' x^2}{2 k_x} \qquad (5)$$

When $x = \pm s$, $\theta = 0$. Hence the maximum rise at the center of the packet is:

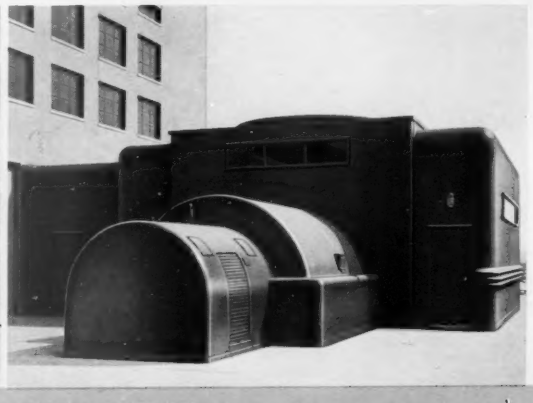
$$\theta_o = \frac{q''' s^2}{2 k_x} \qquad (6)$$

BIBLIOGRAPHY

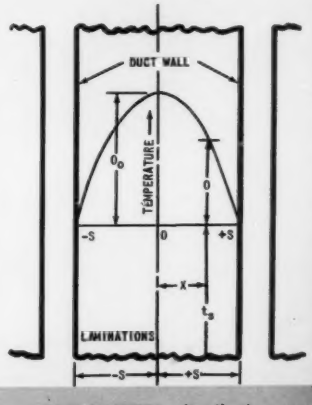
[1] *Hydrogen Cooling Simplified*, by A. Lehrkind and W. F. King, Electrical Review, Third Quarter, 1950.

[2] *Telephone Interference and Alternator Wave Shape*, by L. T. Rosenberg, Electrical Review, June, 1945.

EXCITER HOUSING of generator can be entered by simply raising the roll-top door. Windows at sides of door permit inspection from outside. **(FIGURE 11)**



OUTSIDE INSTALLATIONS of turbine-generators are quite common. Because they reduce building investments, outdoor units like this West Coast installation are gaining favor. **(FIGURE 12)**



TEMPERATURE distribution, as shown above, is parabolic within the stator core packet. **(FIGURE 13)**

Impulse Testing WITHOUT DELAY

by J. H. MORAN*
Transformer Section
Allis-Chalmers Mfg. Co.

New equipment and arrangement streamline and speed up transformer testing a week to a matter of hours.

ABOUT 75 PERCENT of larger modern power transformers are impulse tested in addition to the routine low frequency tests. This percentage is rising so that, in all probability, it will be but a short time until every large transformer will receive an impulse test before it is connected in a power system. It is necessary, therefore, that this test be applied as rapidly and efficiently as possible in order to maintain smooth, uninterrupted production. Consequently, the new impulse test floor was planned and built to achieve the desired production efficiency.

The new test area, Figure 1, is located adjacent to both the low frequency test area and the shipping area. This arrangement permits quick movement of a unit from one test area to the other, and to the shipping area with a minimum of floor clearing. Adequate crane facilities are available to move assembled units for impulse testing easily and conveniently. When necessary, two cranes can be used to move extremely large transformers.

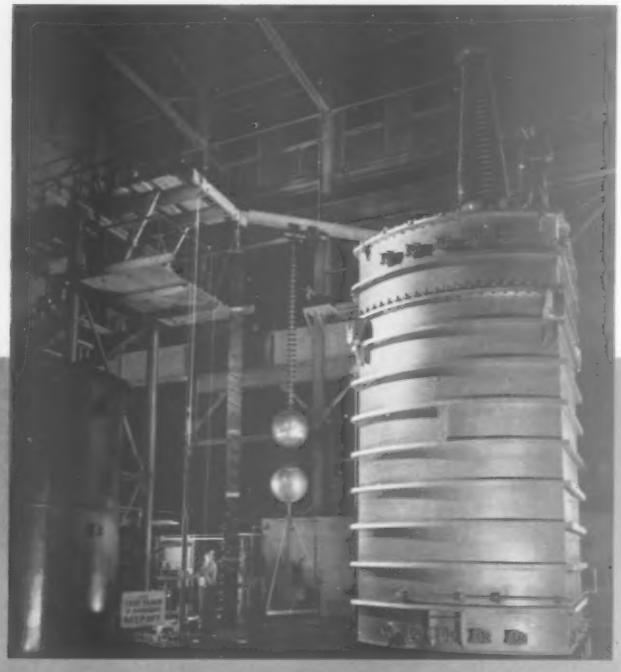
Cathode-ray oscillographs spot trouble

Impulse voltage levels and the manner in which they are applied to the transformer are prescribed in the Transformer Test Code, American Standards Association, C57. Briefly, a reduced voltage of the proper wave shape and of a magnitude below any conceivable failure level is first applied to the terminal under test. An oscillogram of this voltage and of the current through the winding is made by means of the cathode-ray oscillograph. These recordings are later matched to the recordings of the voltage and current obtained when the full magnitude impulse wave is applied to the transformer. Any difference between the two sets of oscillograms is most probably evidence of failure of insulation in the transformer. It is apparent that the control of the voltage, control of the wave shape, and the obtaining, scaling, and matching of recordings are factors which must be dealt with as efficiently as possible.

After the transformer has been delivered to the impulse test floor, and properly connected for test, the first step is to obtain the wave shape required. The most common of these is a 1½ x 40-microsecond wave. This designation is a shorthand method of saying that the voltage applied to the terminal under test rises from zero to its required crest value in 1½ microseconds and decays to one-half of its crest value in 40 microseconds from the beginning of the wave.

A "miniature surge generator," shown in Figure 2, is a great aid in making the preliminary determination of the constants which affect the wave shape. This instrument enables the operator to determine the constants which must be used in the large generator to obtain the proper wave shape. It is neces-

* Author wishes to acknowledge the major contribution of L. C. Aicher, Transformer Section, Allis-Chalmers Mfg. Co., to the completion of the article.



IMPULSE TEST AREA is equipped and concentrated to provide fast and accurate tests. View shows impulse generator in left background and a power transformer being prepared for test. **(FIGURE 1)**

MINIATURE SURGE GENERATOR, manned by a skilled operator, saves time in determining constants needed for proper wave shape. **(FIGURE 2)**

sary to obtain a new set of constants for each design of transformer to be tested because the load of the transformer under test on the surge generator affects the wave shape and magnitude of voltage produced by a given generator connection, Figure 3. Since the ASA Transformer Test Code requires that the same wave shape, with tolerances, be applied to each transformer tested, and since each design of transformer has a different capacitance and inductance from any other, the capacitance, inductance, and resistance in the impulse generator must be changed to compensate for the differences.

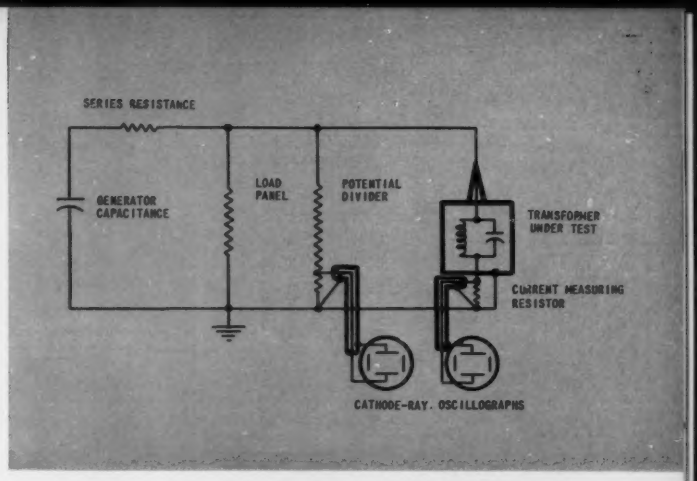
Because of the high voltages required the large impulse generator is a sizable structure. Proper clearances must be maintained to prevent the voltage developed within the impulse generator from flashing from one section to another, or to the building. Consequently the individual pieces of the large impulse generator must be physically large. To change the setting of these large pieces requires considerable time. The miniature generator, being a very low voltage instrument, consists of physically small parts. Because of the low voltage, the miniature generator can be adjusted by manual switches. All characteristics of the small generator duplicate the functions of the large generator except for the magnitude of voltage and current. As a result, the use of the miniature generator enables the operator to determine the proper constants almost as rapidly as he can adjust the dials and measure the oscilloscope trace. This reduces the time consumed from hours to minutes. The indicated constants are then put into the impulse generator, and the reduced voltages, which are approximately 60 percent of the required full voltage, are applied to the terminal of the transformer.

Oscillograms developed on site

Since the oscillographic recordings are on photographic film, the film must be developed. To aid film processing, the test floor is equipped with its own dark room, specially designed for this type of work. The dark room has no door, but is accessible through a light trap similar to the old-fashioned mirror maze. This permits free access to the room without the danger of someone inadvertently spoiling the film by exposing it to light. As a further safeguard against film exposure, the dark room lights are arranged so that it is impossible for anyone but the operator actually at work on the film to turn them on during the developing process.

The films are then scaled, using equipment provided for the purpose. One type cathode-ray oscillograph uses film which is large enough to scale directly. Another oscillograph uses 35mm film which is too small to be scaled directly so the picture must be magnified. The enlarging equipment is located in the dark room for quick and easy use whenever it is needed.

Since the transformer under test is an integral part of the whole test setup, the voltage regulation or efficiency of the impulse generator in any particular case will depend in part on the characteristics of that transformer. The exact regulation at which the impulse generator is operating can be determined only from data obtained from the reduced wave. Once this voltage regulation is known the exact meter setting which must be made to produce the necessary full voltage at the terminal of the transformer under test can be determined accurately. With the proper settings made, the full voltage required is applied to the terminal under test, and the oscillograms taken under this condition are compared with those previously taken at reduced voltage. Magnifying film readers are used to match the two sets of pictures.



SCHEMATIC DIAGRAM of the impulse test circuit used in the new test set-up shows the main components and important connections. **(FIGURE 3)**

Testing time cut in half

The impulse test floor has been equipped with specially developed new hot-cathode type oscillographs, one of which is illustrated in Figure 4. It is a sealed tube unit and does not require continuous evacuation. Its cathode operates at moderately high voltage which, when combined with a post-deflection acceleration type of cathode-ray tube, results in a unit of high writing speed. The choice of screen phosphor and the use of a 35mm camera with a fast lens adds to this writing speed. Tests on this hot-cathode design have resulted in very readable recordings at writing speeds higher than had been possible before.

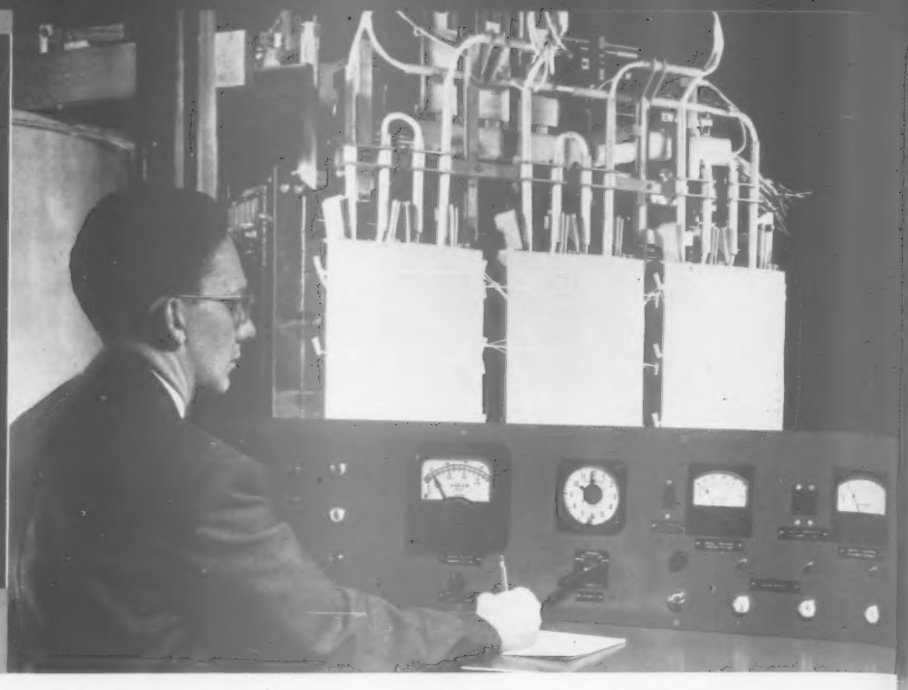
Figure 4 shows one of the hot-cathode type oscillographs. A second unit permits simultaneous recording of neutral current while the first oscillograph is recording the applied voltage. This cuts one phase of the actual testing time nearly in half because it requires only half as many applications of voltage to produce certain required records. It also permits more precise knowledge of happenings during the test. A third oscillograph can be used as a spare for either of the other two during an emergency, or it could be used for recording phenomena on other windings. This unit can also be used with a different sweep speed to study special portions of applied wave, either voltage or current.

The new hot-cathode type oscillograph has time sweeps from one-half microsecond in duration to 500 microseconds. This means that a surge lasting only half of one millionth of a second can be spread out so that it will be about four inches long across the face of the cathode-ray tube. This amazingly fast movement can be permanently recorded on photographic film. The unit will successfully and consistently record the very fast phenomenon associated with impulse testing.

Two methods of synchronizing the oscillograph with the impulse generator are possible with this oscillograph. In one case the sweep of the unit is initiated by the same pulse which fires the main generator. In the other method, a portion of the generated voltage wave coming from the impulse generator is fed into the oscillograph sweep circuit through a ¼-microsecond delay circuit. During this ¼-microsecond delay the oscillograph sweep is started before the voltage to be recorded is applied to the plates of the oscillograph.

Controls on each oscillograph permit a choice of recording the transient signal, an accurately metered calibration trace or crystal-controlled time markers. Still other controls permit positioning the trace within the screen area. Voltage reflections, which would give a false result, are prevented by terminating the coaxial cables to both the vertical and the hori-

NEW HOT-CATHODE type oscillograph shown above permits visual observation of the trace while trace is being photographed. **(FIGURE 4)**



CENTRAL CONTROL DESK contains all impulse generator controls and interlocks. Operator has clear view of specimen under test as well as the generator. Core and coils are in place for distribution test. **(FIGURE 5)**

zontal deflection plate circuits in suitable impedances. To permit control of the actual magnitude of voltage applied to the plates of the oscillograph an accurately tapped potentiometer is connected in parallel with the terminating impedance. The horizontal plate circuit is normally used as a time base sweep. Provision is made, however, to replace the time sweep with an external signal should it be desired to record one phenomenon against another as, for example, voltage against current. The camera shutter is solenoid operated and controlled from the impulse generator control desk. It is arranged so that, whenever the impulse generator is on charge, the camera shutter is open, ready to record any phenomena appearing on the signal measuring circuit.

Central control "frees" operator

Controls for the surge generator and associated equipment are contained in a new, conveniently located control desk, Figure 5, so arranged that the operator has a clear view of the entire test area at all times. The master control desk is designed to relieve the test operator of as many mental responsibilities as possible by making these actions electrically controlled. Motor-driven timers control the sequences of events from the sounding of a warning horn before the impulse generator is put on charge until after the camera shutter is closed. This permits the operator to concentrate on the test specimen and provides more complete records. The method of control can be set up with a selector switch to be completely automatic after being initiated by pushbutton or to be semi-automatic with the operator being given an indication when the generator is ready to be fired. A manual condition can also be selected where every function is under the control of the operator.

To make certain that the voltage supplied to the impulse generator does not fluctuate and make the instruments difficult to control, the incoming voltage to the entire test area is regulated by a step type feeder voltage regulator with special coils designed to fit the voltage requirements of the test equipment.

The available capacitance and energy of the impulse generator have been doubled. However, the maximum voltage of the generator has been kept at three million volts, adequate to test all commercially-produced transformers.

Streamlining affects all phases

Numerous other components have been incorporated in the new test area. A motorized drum hoist to raise and lower the resistance load panel and the resistance potential divider is included. Ordinary rope is not desirable as a support for these resistances because of its tendency to absorb moisture and the ease with which foreign particles adhere to it. The present arrangement includes nylon rope which eliminates such problems. Automatic spring return reels keep the wires forming the electrical connection between the load panel and potential divider continually taut. Practically all of the resistors throughout the generator are wire-wound units with some, of necessity, being wound for a minimum of inductance.

The series gaps between steps of the generator are geared together and motorized. The master control desk places their control at the operator's fingertips. An electrical remote gap position indicator, calibrated in terms of the voltage which a given gap spacing will withstand, is also located on the master control desk.

A one meter sphere gap is available for overall voltage checks on the equipment. One sphere is suspended on a string of insulators from a jib crane which can swing through a large area. The grounded sphere is mounted on a calibrated and motorized shaft which is a portion of a tripod support with casters to facilitate movement.

Personnel safety has received attention, too. Electrical interlocks have been provided on the generator as a precaution against an attendant climbing into the generator structure while the machine is on charge. A three-level photocell arrangement has been installed to sound a warning to the crane operators and to the test operator whenever the hooks or load of any overhead crane enter the restricted test area.

The new impulse test floor, in conjunction with the recently completed "pushbutton" regular test floor, is one of the finest transformer test facilities in the country. It has made possible a very considerable reduction in the amount of time consumed in testing a transformer as well as improving the quality of the test results obtained.

CORONA Another Transformer "HAS BEEN"

by L. C. AICHER
Transformer Section
Allis-Chalmers Mfg. Co.

Proper interpretation of impulse wave shapes is an art. Absence of corona, however, simplifies it considerably.

CORONA-FREE POWER TRANSFORMERS are a reality now. The development and eventual perfection of these new transformers is the result of several years of design, construction, and testing. Although the principles of corona-free transformer design have been discussed in previous articles,[1] little has been said about the developments in testing that were necessary to make certain that the transformers were really corona-free.

To begin with, corona is a discharge caused by ionization of the dielectric medium surrounding a conductor. This occurs when the voltage gradient in the dielectric medium adjacent to the conductor exceeds a certain critical value. These discharges produce local, intense heat which tends to destroy the insulating medium. The rapidity with which this destruction occurs depends on the severity of the corona condition and its duration, the latter being measured by the number of successive applications of surge test voltages. By eliminating one more of the few remaining obstacles to long transformer life, corona-free transformers have a definitely greater life expectancy than previous designs.

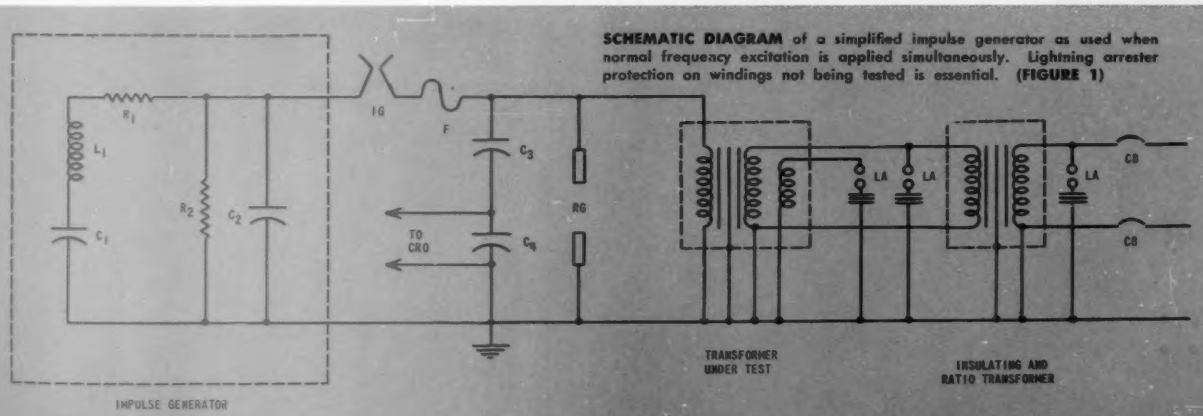
Testing for corona

Corona can be detected by several methods, each under different circumstances. At normal frequency operating voltages corona can be detected by the radio interference it produces. It is also possible to detect corona in apparatus by applying the current wave to a cathode-ray oscilloscope and observing for a departure in wave shape as voltage is increased. Of course, whenever ferro-magnetic materials are involved, there will be a change in wave shape due to harmonic content. If corona is present, there will be a superimposed spasmodic disturbance.

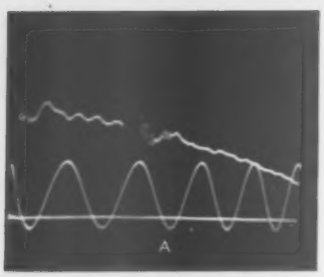
Originally, impulse testing was applied to verify the dielectric strength of the transformer. These tests, however, can provide more information when properly interpreted. For a time it was believed that the impulse breakdown strength of an insulation structure was a substantial percentage above corona level. It was known that the insulation structure would fail eventually if voltage was applied repeatedly above the injurious corona level. Structures that possess these characteristics have been superseded by currently used construction that can be corona-free up to nearly 100 percent of breakdown level. These can have repeated applications of voltage applied at nearly breakdown level without danger of progressive injurious corona being present. This fact is the basis for stating that a modern transformer can have repeated impulse tests applied with little possibility of latent damage.

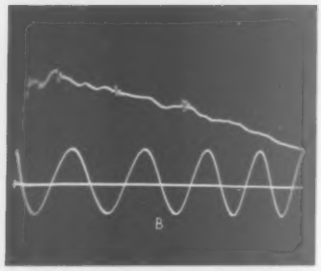
Whether a transformer has passed the impulse test satisfactorily and otherwise met requirements is a difficult, yet a most important, part of the impulse test procedure. Experience with transformer impulse failure detection methods has been related elsewhere,[2] however it is well to review certain experience in order to associate its similarity with that of corona detection. As a matter of fact, the existence of corona is sufficient reason for engineers to reject the unit until the corona is eliminated as proved by further testing.

A major problem in perfecting a fault detection technique has been the elimination of superfluous disturbances produced by elements other than the transformer. Figure 1 shows a simplified surge generator circuit with a three-winding transformer connected for tests used some years ago when 60-cycle excitation was applied simultaneously with the impulse voltage. Components C_1, L_1, R_1, R_2, and C_2 represent the effective parameters in the surge generator circuit during discharge. Capacitors C_3 and C_4 in series form a voltage divider for measurement of the applied surge. The rod gap used to produce a chopped wave is identified by RG. An insulating and voltage ratio transformer was necessary to provide the proper excitation voltage to the transformer under test and to act as a buffer to prevent dangerous surges from reaching the source of excitation. In order that excitation voltage would not flow through portions of the surge generator, an isolating gap, IG, was provided. A fuse, F, was provided to interrupt the flow

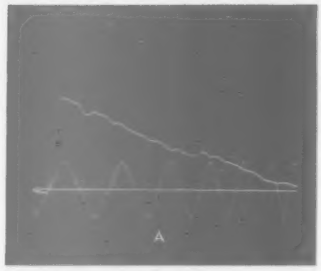


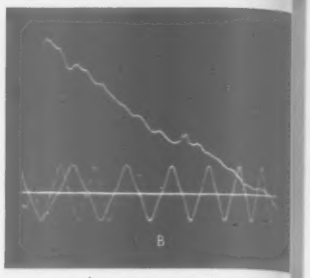
SCHEMATIC DIAGRAM of a simplified impulse generator as used when normal frequency excitation is applied simultaneously. Lightning arrester protection on windings not being tested is essential. **(FIGURE 1)**





FULL WAVES applied to HV winding. LV bushing flashover (a) caused disturbance at about 19 microsec. Full wave after three lightning arresters were applied to excitation circuit is shown in (b). **(FIGURES 2a and 2b)**





APPLICATION OF LIGHTNING arresters produced the above effects on the impulse wave. The effects on reduced full wave are shown in (a), and (b) records the results obtained on a full wave. **(FIGURES 3a and 3b)**

of excitation current into the generator after the impulse had crossed the isolating gap on its way to the transformer terminal.

Fault detection complicated

First, consider the circuit of Figure 1, but without the three lightning arresters shown connected to the transformers. If such a circuit was used during an impulse test, a bushing flashover on a winding other than the one being tested would probably occur. Such a disturbance is shown in Figure 2a, at approximately 19 microseconds, obtained while applying impulse voltage to the high voltage line bushing, during which a low voltage line bushing flashed over. Figure 2a is particularly interesting, as a tap failure is indicated at about two microseconds. Imagine the difficulty of recognizing the existence of the fault had the time interval between the fault and the bushing flashover been nearly zero.

Now consider the three lightning arresters applied to the excitation circuit and third winding, resulting in the typical oscillogram shown in Figure 2b. The oscillogram shows that the arresters have operated to prevent the bushings from flashing over, thereby reducing the magnitude of the disturbance on the tail of the wave. It is evident that identification of a fault has been complicated by the introduction of additional disturbances produced by the necessary arresters. Figures 3 and 4 are typical illustrations of the effect of arresters. Figure 4b is interesting because the arrester disturbance just beyond the crest of the wave is very similar to the change experienced when a portion of winding such as a pair of coils is short circuited by a dielectric failure.

Figure 5 shows two oscillograms obtained during a series of voltage applications upon a transformer. Note the variation in times to discharge as well as magnitude of disturbances produced by the arresters. No excitation was applied.

Upon closing the excitation circuit a change takes place in the impedance of the load on the impulse generator, usually to shorten the tail of the applied impulse wave. This is illustrated in Figure 6 which again is on the same transformer as Figure 5. The change of slope on the tail of the wave as compared with that of the reduced voltage full wave without excitation, Figure 5a, is evident and can lead to confusion during the demonstration that the transformer has withstood the test. Such a change in the slope could lead to an interpretation of high leakage over insulation to ground, or a change in the amount of winding that is in series with the impulse generator. High leakage over insulation is usually a manifestation of corona.

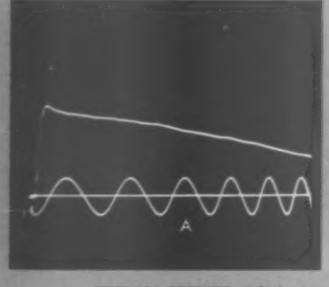
There seems to be no question that if the cathode-ray oscillograph is properly used it will detect any failure experienced to date. It is very important that the measuring circuit be as sensitive as it is possible to make it. Extraneous oscillations must be sufficiently small so that they will in no way affect the interpretation of results. They cannot be filtered out by devices inserted into the measuring circuit, for such devices will likewise filter similar disturbances which may be the corona to be observed. Instead, it is necessary to control these oscillations at their source by careful arrangement of the generator circuits and by being particularly careful with the ground system.

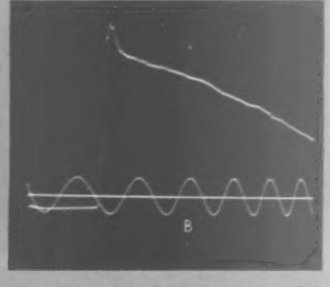
Oscillograph is dependable and versatile

The cathode-ray oscillograph has indicated defects where the simultaneously applied 60-cycle excitation offered no evidence of trouble. As shown in Figure 7 the oscillograph will detect any fault to ground that occurs near the line end of the winding. An example which involves 10.2 percent of the winding between coils, some distance from the line end, is shown in Figure 8a, the reduced voltage full wave. A full wave which followed two chopped waves is shown in Figure 8b.

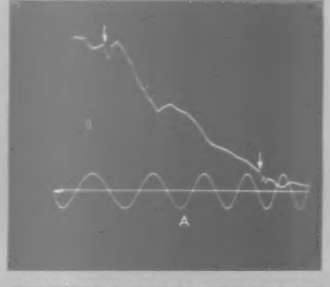
The tap failure shown in Figure 2 was in a section of the winding extending beyond the grounded point and was as far removed from the point of measurement as possible, yet the cathode-ray oscillograph responded faithfully.

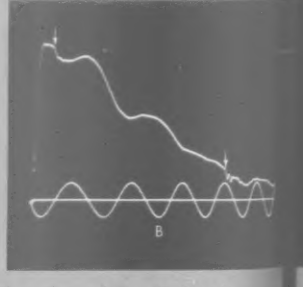
After some eight years of impulse testing with excitation, and finding that excitation only added complications, some testing was carried out without excitation. Fewer lightning arresters or other protective devices were used to control the



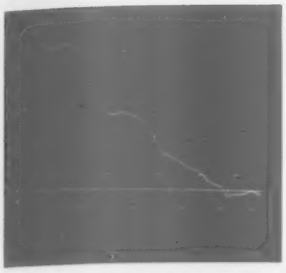


TYPICAL EFFECTS of lightning arresters on an impulse wave are recorded by the above oscillograms. Again, (a) illustrates results on a reduced full wave, while (b) shows effects on a full wave. **(FIGURES 4a and 4b)**

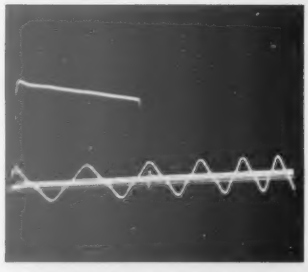




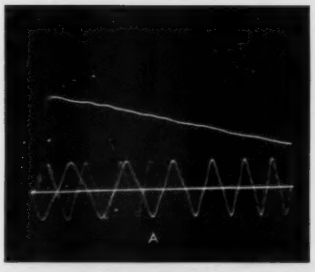
SUCCESSIVE VOLTAGE APPLICATIONS show the variation in time to arrester operation. No excitation was applied. Reduced full wave is shown in (a) and full wave is recorded in (b). **(FIGURES 5a and 5b)**

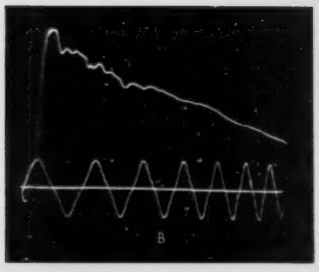


EXCITATION CIRCUIT has a marked effect on the slope and length of tail. **(FIG. 6)**



OSCILLOGRAM shows line end to ground failure during full wave. **(FIGURE 7)**





COIL-TO-COIL FAILURE involving 10.2 percent of winding is shown by comparing the reduced full wave (a) and the full wave with excitation illustrated in (b). **(FIGURES 8a and 8b)**

flashover of bushings on the windings other than the one being tested. This did not eliminate the disturbances produced by the protective devices but it did reduce their number and simplified the preliminaries for the test which, in turn, further reduces complications when trouble arises.

Since the cathode-ray oscillograph has proved to be a very dependable device, when properly used, it is not surprising that additional arrangements of the device have been suggested for detection. Ten years ago the cathode-ray oscillograph was used to measure the division of surge current among the various grounded terminals of a unit substation, including the winding under test. Four years later substantially this same method, called the neutral current method, without a calibration, was proposed as an auxiliary means of failure detection.[3] When used for this purpose, there is no need for an accurate calibration since it is used for wave form comparison only. Almost coincidentally with this announcement the method was being used as an aid on an experimental transformer trying to locate a suspected fault. The oscillograms are shown in Figure 9. Figure 9a is the neutral current measurement obtained when a reduced voltage full wave was applied and Figure 9b is that for the full wave test. It is quite obvious that these oscillograms do not superimpose. This was a turn-to-turn fault involving approximately 1/10 of one percent of the winding.

Procedure for the neutral current detection test is to insert a current shunt in the terminal ground lead and apply the voltage developed across the shunt to the plates of the oscillograph as shown in Figure 10. A recording is made at reduced full wave level and full wave level. It is desirable that the potentiometer ratios of the oscillograph be adjusted so that the physical amplitude of the two oscillograms is comparable, then they can be superimposed and easily studied for differences. Usually these neutral current oscillograms will consist of many frequencies and a mismatch is indicative of a change in transformer impedance, as when a failure occurs. Small changes in impedance will result in larger changes in the neutral current oscillograms than those occurring in the voltage oscillograms taken on the same winding.

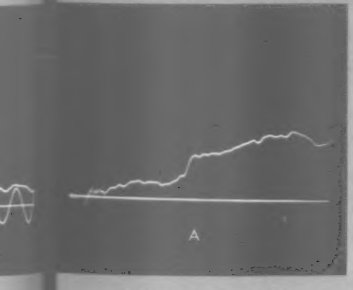
Experience shows that the shunt characteristics are very important. Its resistance must be as small as possible, yet it must produce a suitable voltage for deflection of the oscillograph trace. If the resistance of this shunt becomes too large it affects the distribution of the surge currents in the transformer and may even cause flashover of the bushings. This can change materially the magnitude of oscillation in the winding under test.

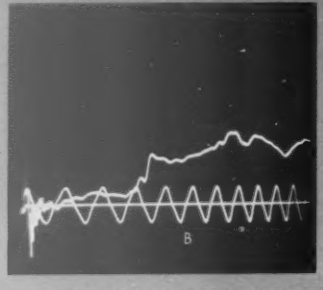
The neutral current method of measurement has been invaluable in perfecting significant developments toward producing a corona-free transformer. That such improvements are real is attested to by a comparison of Figures 11 and 12. The oscillograms of Figure 11 were obtained before the present methods of corona control were perfected. These oscillograms were obtained on insulation samples which were tested to determine a safe working strength when applied to a transformer. The lower trace in Figure 11b indicates corona at about seven microseconds and again at approximately 38 microseconds. Contrast this indication of corona with the neutral current indication shown in Figures 12e and 12f. The recordings in Figure 11 were made with a standard voltage measurement, whereas those in Figure 12 were obtained with neutral current measurement.

Two methods better than one

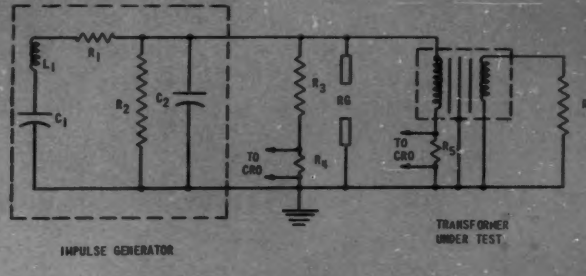
The sample which produced the oscillograms of Figure 11a was subject to corona at approximately 300 kv whereas breakdown is shown in Figure 11b at 700 kv. In this series of tests single shot applications at a given voltage level were applied. Most certainly if repetitive voltage applications had been applied at any level above the corona point, the sample would have failed.

The oscillograms which show significant improvement, Figure 12, were obtained on a typical major insulation assembly following the corona-free principle of construction. The current shunt for the neutral current measurement was connected between the test tank and ground. It was necessary to take a voltage wave and a current wave and continue this alternating arrangement throughout this particular test.

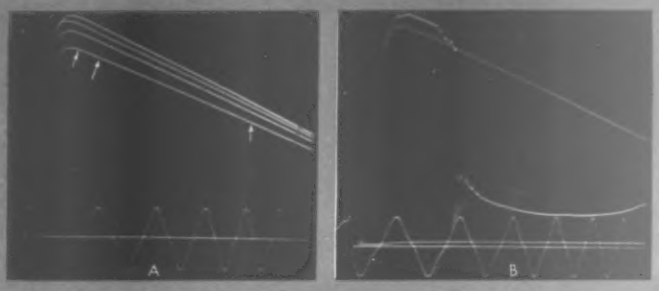




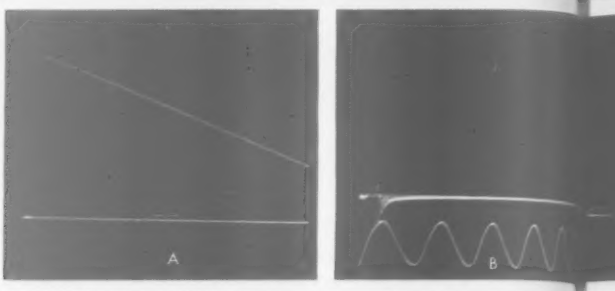
NEUTRAL CURRENT oscillograms of an HV winding are shown for both the reduced neutral (a) and full neutral currents (b). **(FIGURES 9a and 9b)**



IMPULSE GENERATOR diagram shows neutral current shunt. **(FIGURE 10)**



DIELECTRIC FAILURE development in non-corona-free insulation is shown in these illustrations. Arrows in (a) show first indications of corona. Oscillogram (b) shows complete failure. **(FIGURES 11a and 11b)**



CORRELATION OF VOLTAGE and neutral current oscillograms in corona-free insulation. Maximum full wave prior to failure is shown in (a). Neutral current corresponding to (a) is shown in (b). **(FIGURES 12a and 12b)**

Repetitive applications of voltage were made on the sample at each voltage level. The voltage on the insulation assembly was raised to the maximum value possible before discharges were evident. A voltage oscillogram of this wave is shown in Figure 12a. The neutral current corresponding to the full wave oscillogram is shown in Figure 12b. A similar neutral current recorded with a faster sweep is illustrated in Figure 12c. Upon raising the voltage 1.6 percent a failure was produced as shown in the voltage oscillogram of Figure 12d. A dip after the crest of the voltage wave has occurred similar to those associated with the existence of corona discharge just prior to the failure. The current neutral measurement accompanying this failure is shown in Figure 12e which, when expanded on a faster sweep, is illustrated in Figure 12f. Corona is indicated on the current recording by the pip shown at about three microseconds.

If all oscillograms recorded on a transformer were of a smooth character as those obtained on simple insulation structures like Figure 12, the detection of corona with the voltage oscillogram would be simple. The characteristic of most transformers produces a voltage wave in which the natural period of the transformer is reflected as a superimposed voltage oscillation. With such a voltage wave, departures from the reduced wave are not as evident, although superimposition of the film does indicate most of them. Sometimes, however, interpretation is a delicate decision. When such a situation prevails, the current neutral recording illustrated in Figure 13 is valuable. These oscillograms were obtained on a line lead when corona existed on a bare junction. Examination of the voltage oscillograms indicated that the transformer had apparently passed the impulse test satisfactorily. A comparison of the recordings shows the differences in the reduced current wave and full current wave oscillograms of Figures 13a and 13b respectively. If a sufficient number of surges had been applied, failure would have most certainly occurred, for even with the number that were applied sufficient corona actually occurred to mark the insulation adjacent to the fault.

Commercial corona-free transformer construction is practical as borne out by Figure 14. A full-size model of a high voltage power transformer was constructed using corona-free construction, then subjected to numerous tests. After applying the commercial dielectric tests repeatedly, this model was subjected to over-voltage tests, eventually to destruction. Figure 14a shows the reduced voltage full wave made at 420 kv, and Figure 14b is the corresponding reduced level current measurement. Twenty-five applications of voltage were made at each level with the increments approximately four percent apart. Figure 14c shows a representative full wave taken at 925 kv, and Figure 14d is the corresponding current measurement. When these are compared with the reduced voltage oscillograms there is no indication of corona.

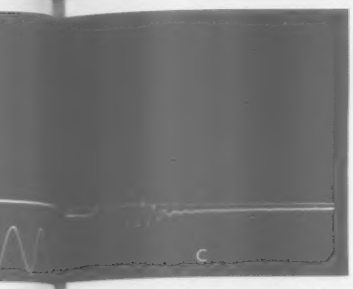
It was necessary at this point to change the impulse generator from a series-parallel circuit to a straight series connection in order to increase the voltage output. This change resulted in somewhat different wave shapes as shown in Figure 15. Figures 15a and 15b are the full voltage and corresponding current oscillogram taken at 950 kv and still show no corona. Test voltage was then increased to 1,000 kv and full wave voltage recorded as shown in Figure 15c. Unfortunately, the corresponding current measurement was recorded so lightly on the film that it could not be reproduced in print, but neither the full wave of voltage nor the current show corona to be present. On the fifth application of this voltage the transformer failed as shown in Figure 15d.

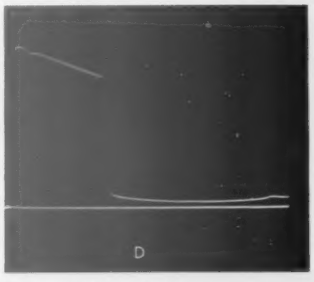
The oscillograms shown in Figures 14 and 15 are representative of corona-free construction and bear out that, when this principle is followed, corona will not prevail at the test levels. The results illustrated in Figures 14 and 15 are from a single experimental model. Practical margins for manufacturing and testing must be allowed.

The technique of failure detection during impulse tests has progressed rapidly. Modern methods are very effective in recognizing the existence of faults. When properly used, these methods will detect the presence of injurious corona. This proper application and interpretation has been largely responsible for the development of corona-free transformers for use on circuits of all voltages.

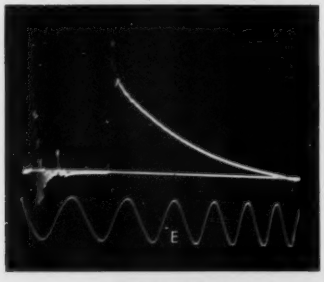
BIBLIOGRAPHY

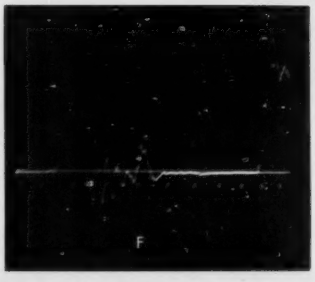
1. *Co-ordinated Insulation—New Transformer Milestone,* S. L. Foster, ELECTRICAL REVIEW, First Quarter, 1949.
2. *Experience with Transformer Impulse Failure Detection Methods,* L. C. Aicher, AIEE Transactions 1948, Technical Paper 48-291.
3. *Progress in Impulse Testing of Transformers,* J. H. Hagenguth, AIEE Transactions 1944.





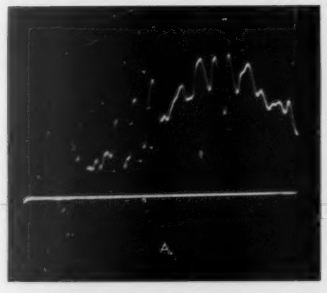
NEUTRAL CURRENT similar to (b) except with a faster sweep is recorded in (c). Voltage oscillogram of failure showing discharge at failure level is shown in (d). **(FIGURES 12c and 12d)**

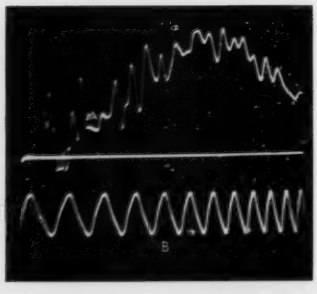


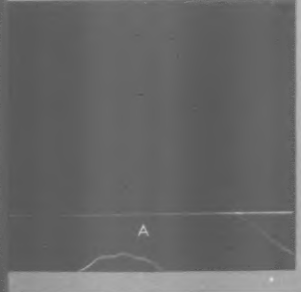


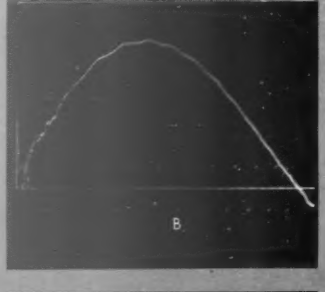
NEUTRAL CURRENT of dielectric failure is illustrated in (e). Oscillogram (f) is similar to (e) with the exception that the latter has a faster sweep. **(FIGURES 12e and 12f)**

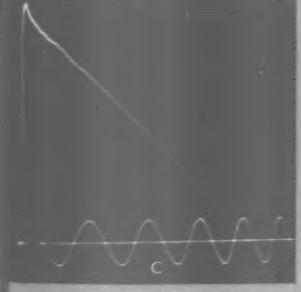
CORONA DISCHARGE can be detected with neutral current measurement. Oscillograms show results obtained with reduced neutral current (a) and full neutral current (b). Readings such as these require close observation to provide conclusive evidence that a transformer has successfully passed the impulse test. **(FIGURES 13a and 13b)**

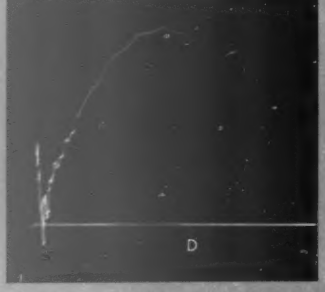




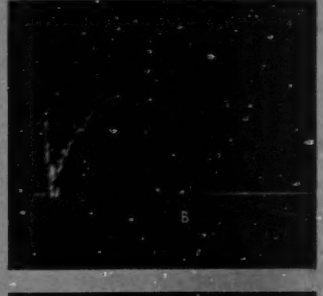








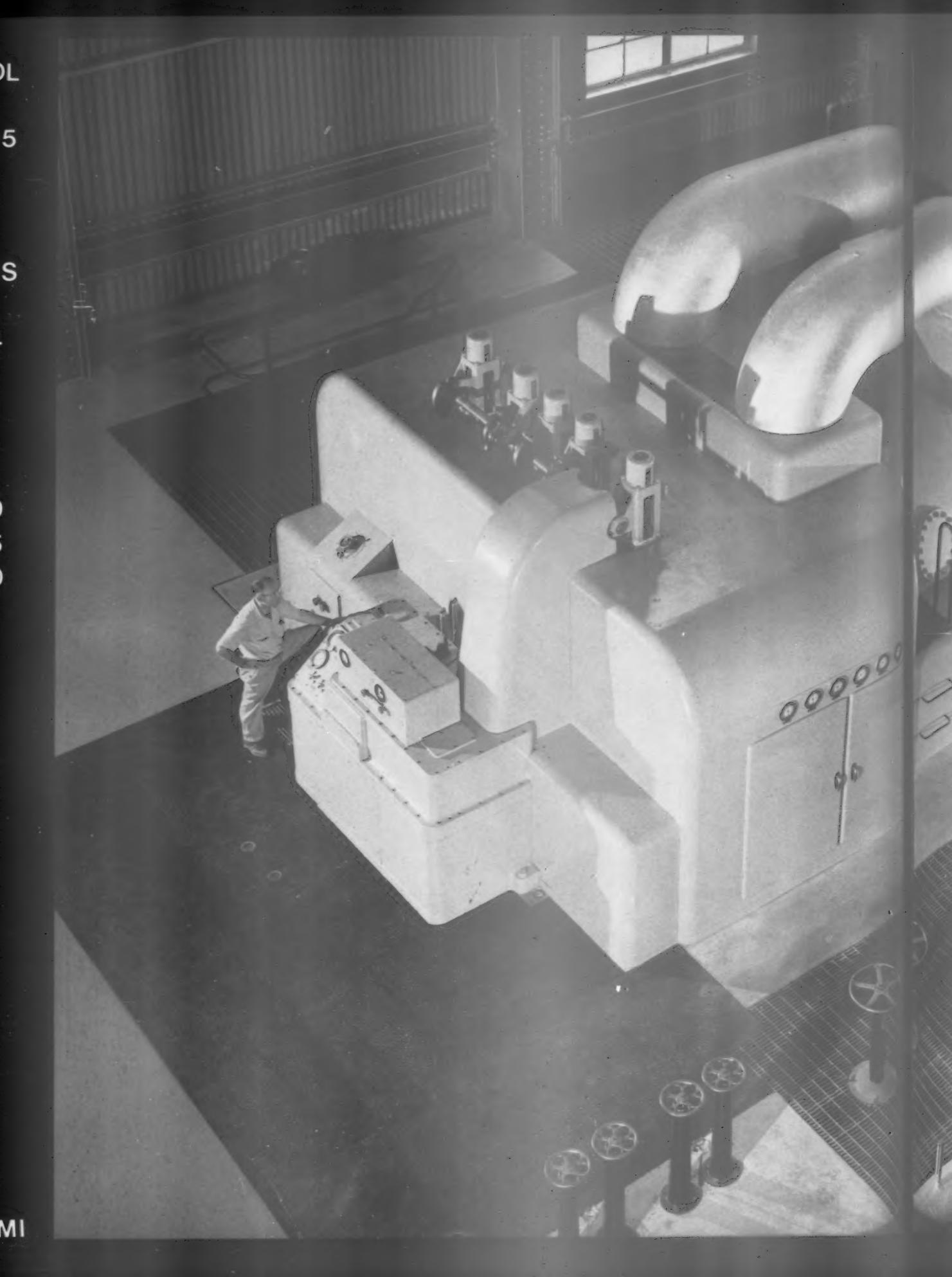
CORONA-FREE TRANSFORMERS can be built as shown in the various oscillograms above. Results obtained by subjecting the unit to a reduced full wave test at 420 kv are shown in (a). Neutral current oscillogram corresponding to (a) is shown in (b). Representative full wave at 925 kv, no corona, is shown in oscillogram (c), while neutral current measurement corresponding to (c) is illustrated in (d). **(FIGS. 14a, b, c, and d)**

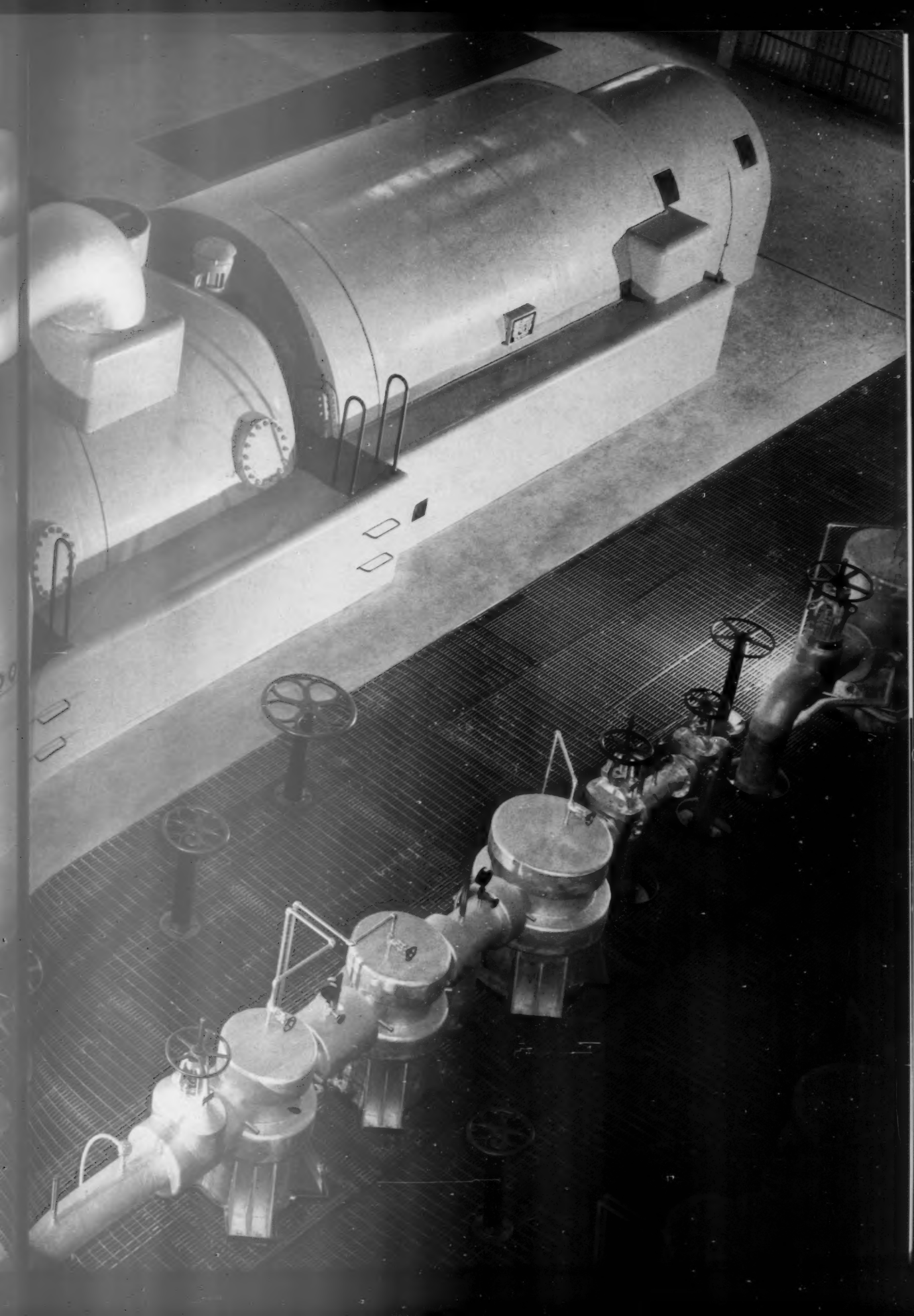


CONTINUATION OF TESTS in Figure 14, but with different impulse generator setting, is shown above. Illustration (a) shows full wave at 950 kv, no corona, while (b) represents neutral current corresponding to (a). Full wave at 1000 kv, no corona, is recorded in (c), while (d) is an oscillogram of results obtained on the fifth full wave application at 1000 kv showing dielectric failure. **(FIGURES 15a, b, c, and d)**

THIS 40,000-KW STEAM TURBINE generator unit operating at the Riverside station of Gulf States Utilities Company is typical of AIEE-ASME preferred standard units for modern power stations in ratings from 11,500 to 90,000 kw. Steams conditions are 850 psig, 900 degrees F and 1½ inches mercury exhaust. Generator is hydrogen-cooled.

Allis-Chalmers Staff Photo





Patents Make Sense /F...

by JOHN S. LIEB
Patent Attorney
Allis-Chalmers Mfg. Co.

. . . you follow the author's suggestions. You, too, can avoid that sinking feeling when asked to read and explain a patent.

WHY IS IT," asks the engineer, "that some publications are easy to read and others, like patents, are so difficult?" One modern writer looking for an answer to the question made an investigation of the readability of publications.[1] He divided writings into the following categories according to readability.

Typical Magazine	*Readability*
Comics	Very easy
Pulp fiction	Easy
Digests	Standard
Academic	Difficult
Scientific	VERY DIFFICULT

He found that the readability of any piece of writing is based on the average length of sentence, number of affixes used, and number of personal references appearing in it. By these standards, patents should occupy a line in the table directly below scientific writing and be VERY, VERY DIFFICULT to read. Now the engineer, who has been weaned on comics, raised on digests, and graduated to scientific writing, is already accustomed to reading writing labelled VERY DIFFICULT to read. It should only be a step, then, for him to advance to reading writing labelled VERY, VERY DIFFICULT. Yet the engineer has difficulty completing this last step.

Part of the trouble lies, of course, with the patent copy. It looks like a legal document — which it is. The most difficult of legal documents to prepare, according to one judge. This in itself is enough to make an engineer suspicious. On top of this, patent copy looks dull, which is, however, what one would suspect of a legal document. By present-day standards, patent drawings appear old-fashioned and patent format, itself, stiff and forbidding. Add to this the fact that the language comprises long and tortuous sentences, unfamiliar terms, and almost complete lack of personal references, and the engineer is undoubtedly up against the toughest sort of reading. Is there a solution to this reading problem? There is, but before it is presented let us see why the engineer should bother with patents.

[1] Rudolph Flesch: *The Art of Plain Talk*, Harper & Bros. 1946.

Why bother with patents?

For the engineer, an understanding of patents can be a powerful engineering tool, useful for professional advancement. Why? Because patents are the source material of past engineering development and indicative of present engineering trends. The engineer may not realize it, but United States patents, available for reference at the Patent Office in Washington, D. C., and at our larger city libraries, afford him a review of a century and a half of engineering progress in any field. From a company's standpoint, the engineer who understands patents is a valuable man because he is in a position to steer the company clear of the staked-out areas of others' patented inventions.

Engineers are not always conscious of the fact that unexpired patents represent potentially valuable property. The engineer who, through ignorance or otherwise, trespasses on this property creates not only legal problems but public relations problems as well. Legally he may obligate both himself and his company for an uncomfortably large sum of money. One large automobile manufacturer, after a few years of unauthorized use of a patented invention, settled with the inventor for over a quarter of a million dollars. From the public relations viewpoint, the unauthorized use of a patented invention may incur ill will throughout an industry. If for no other reason than these, the engineer cannot afford to neglect patents.

As previously stated, there is a solution to the problem of reading patents. It lies in stripping the patent of some of its mystery and showing it for what it is — a description of an invention. This can best be done by first reviewing patent history and then, dissecting a typical patent, explain its make-up and meaning. Nothing ever looks quite so mysterious after the bare bones have been exposed to view. The first order of business, then, is the history of a patent.

The modern patent is a product of evolution and can be traced to the European commerce of the Middle Ages. Operating a business then was much riskier than it is now, although the modern businessman might argue the point. Robber barons shook down the medieval businessman on land. Pirates and unfriendly nations made off with his ships at sea. To induce private citizens to undertake business ventures in which they stood to lose their lives as well as shirts, monarchs granted them certain exclusive privileges in commerce. The tangible evidence of such grants was usually in the form of an open letter addressed to the public. This grant was known as a letters patent, or simply patent.

Patents come of age in England

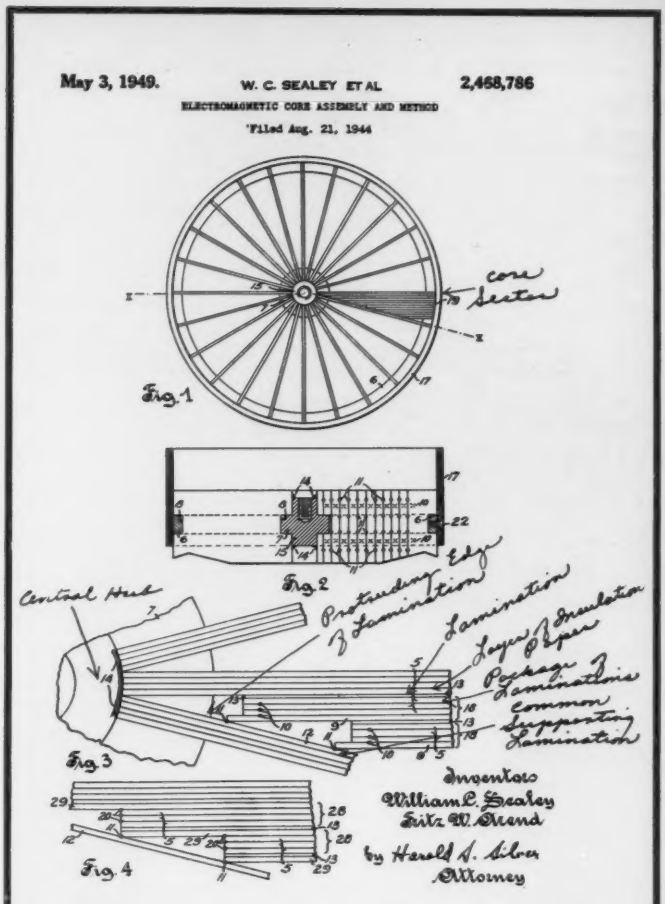
For various reasons, conditions in England during the Middle Ages, and after, were more favorable to the growth of patents than elsewhere. For one thing, the growth of a capitalist

middle class encouraged private speculative enterprise. During the 16th century, the formation under royal charter of joint stock companies to promote trading and manufactures created a demand for patent protection, and the Crown obliged.

English records of Queen Elizabeth's reign (1558-1603) show patents issuing on such diverse subjects as a dredging machine, the manufacture of soap, and an improvement in knife handles. Patent grants were not confined to inventors, however. Importers of industries and machines from abroad, as well as courtiers and servants who made no inventions but to whom the Crown was often indebted, received grants. Many of the patents granted by Queen Elizabeth and her successors to the throne, James I and Charles I, were clearly contrary to English common law. These illegal grants, embracing no new inventions but giving court favorites monopolistic control over the basic necessities of life, ushered in an era of scarcity and high prices. An outraged public eventually forced, in 1624, the passage through Parliament of the famous Statute of Monopolies. This act, the prototype of modern patent statutes, made such monopolies illegal, and emphasizing the common law restricted the issuance of patents to only the true and first inventor of a new manufacture.

The Statute of Monopolies was to leave its impress on certain of the American colonies in the 150-year period which followed the passage of the Statute in England. In that period, colonies like Massachusetts and Connecticut passed similar laws and issued patents. It is not surprising, then, to find that many of the delegates to the Constitutional Convention of 1787 at Philadelphia were familiar with patents. Recognizing the desirability of encouraging invention under our new government, once established, the delegates adopted, without debate, a provision for a U. S. patent system. Subsequent legislation enacted by Congress established the United States Patent Office and empowered the Commissioner of Patents to grant patents for new inventions. Further legislation, in 1870, provided for the printing and sale of patent copies.

These copies are obtainable from the Patent Office for 25 cents. They are exact reproductions of the patent with one exception. The cover page, which is known as the grant, is not reproduced.



DRAWING SHEET of U. S. Patent No. 2,468,786 shows four views of two forms of laminated core assembly for induction apparatus. The various elements which make up the core are identified in the views by reference numerals. For example, "5" identifies the laminations. **(PLATE A)**

Patent owners' rights are limited

The grant confers on the patent owner the exclusive right to make, use, and sell the invention throughout the United States and its territories for 17 years. The term "exclusive right" means that the patent owner has at law only the right to exclude others from making, using, and selling his invention. He himself has no right to use the invention if it requires the use of another's patented invention. When this situation exists, the patent owner must obtain permission from the other patent owner before he can use the invention he himself owns. This permission usually takes the form of a license. If this is puzzling, perhaps an example will serve to explain it.

Nikola Tesla secured the basic U. S. patent on the polyphase induction motor.[2] Shortly afterward and while Tesla's patent was in force, the inventor Dobrowolsky secured a patent on an improved winding usable in Tesla's motor.[3] Suppose that Dobrowolsky, wishing to realize on his invention, had desired to manufacture Tesla's motor with Dobrowolsky's improved winding. Would Dobrowolsky have been free to do so? Not without a license from Tesla. The patent system must work this way, otherwise Tesla's right would have dissolved into thin air, if every time someone else made an improvement on Tesla's motor that someone else had been free to use Tesla's invention. Since the practice of any patented invention by the owner may require the use of someone else's patent, it is always advisable for the patent owner to check the patent situation relative to his patented device before undertaking manufacture. Otherwise he may be unpleasantly surprised to receive a letter from the other patent owner asking him to cease manufacture, or else.

[2] U. S. 382,280.
[3] U. S. 427,978. First squirrel cage winding.

Patents describe inventions

Prior to the American Revolution, the public could not discover from reading an English or Colonial patent much about the actual invention. No attempt was made in the early patent grants to describe the invention, either by writings or drawings. When patents were few, this did not matter much. But with the advent of the industrial revolution and increased inventive activity, a written description came to be required as part of the grant to distinguish new inventions from the old. The description of the invention appearing in a modern patent should be sufficient to teach anyone skilled in the field to which the patent pertains to practice it after the patent has expired.

Date of Issue

Patent No.

Patented May 3, 1949

2,468,786

Government Agency Which Issues Patent

UNITED STATES PATENT OFFICE

2,468,786

ELECTROMAGNETIC CORE ASSEMBLY AND METHOD

Title

William C. Sealey, Wauwatosa, and Fritz W. Arend, West Allis, Wis., assignors to Allis-Chalmers Manufacturing Company, Milwaukee, Wis., a corporation of Delaware

Names of Inventors
Owner of Patent

As of this Date, the Patent is a Reference for what it Discloses

Application August 21, 1944, Serial No. 550,358

6 Claims. (Cl. 175—356)

Identifies Patent Office

Close in which Patent was Story of Issue

1

This invention relates in general to electromagnetic cores and particularly to an improved core assembly for induction apparatus having substantially radial laminations and to an improved method of assembling such core.

Prior art cores for induction apparatus have been made substantially cylindrical in shape and have been formed of laminations extending substantially radially and longitudinally of the cylinder. In order that laminations of uniform thickness throughout their radial length may be used, sectors of the core, substantially triangular in cross section, have been formed of laminations having progressively decreasing radial length. When these sectors were assembled to form a cylindrical core, thermo-setting varnish has been used in an attempt to hold the laminations in place during the assembling operation. This method of assembling these cores had the disadvantage of permitting relative movement of the various laminations during assembly and operation. Welding of the laminations has been avoided so as to eliminate the flow of eddy currents through the welds in the laminations.

It is therefore an object of the present invention to provide a core assembly and method of assembling the same that will avoid the above disadvantages.

It is also an object of the present invention to provide an improved core assembly and method involving radial laminations in which packages of laminations are welded or otherwise fusibly united together without effecting increased eddy current losses.

It is a further object of the present invention to provide an improved core structure and method in which the laminations can be easily welded at low welding currents and without deformation or burning of the thin laminations.

It is also an object of the present invention to provide a core assembly and method in which the laminations are welded in an improved manner so that packages of the laminations can be assembled with insulation therebetween to form an improved cylindrical core with the laminations extending substantially in a radial direction.

Objects and advantages other than those above set forth will be apparent from the following description when read in connection with the accompanying drawing, in which:

Fig. 1 is a top view of a core assembly embodying the present invention;

Fig. 2 is a section view taken on the lines II—II of Fig. 1;

Fig. 3 is a partial enlarged view of the core structure shown in Fig. 1; and

Fig. 4 shows a modified form of the invention as shown in Fig. 3.

Statement of Invention

Description & Embodiments Shown in the Drawings

The core assembly as shown in Figs. 1 and 2 is substantially cylindrical and is formed of a plurality of sectors 10, in which the laminations of sheet core material are substantially radial. In Fig. 1 only one core sector 10 is shown with the laminations in place, for the other sectors would be similar if assembled. Each sector 10 is made up of a plurality of packages 10 of laminations as shown more in detail in Fig. 3. Each package 10 is made up of a group of laminations 9 of one length and one lamination 9 of a longer length. The groups of laminations 9 of one length as shown in Fig. 3 contain three laminations, however, this number may be increased or decreased as desired.

The packages 10 of laminations may be fusibly united as by spot welding as at 10 in Fig. 3. These packages of laminations are then spot welded, starting with the shortest package 10, to a common supporting lamination 12 which will become one of the laminations in the longest group of the adjacent sector 10. This weld is shown at 11 and can be made with very little current as only two thin laminations are involved. With low current there is no deformation of the material and no burning. The package 10 of laminations can be easily held in place and several of these welds 11 are made to hold one package as shown in Fig. 2. As the packages 10 are assembled, a layer of insulation such as paper 13 is placed between adjacent packages.

When the welded packages of one sector 10 are assembled and held together by the above method, this incomplete sector is put in place as shown in Figs. 1 and 2 with the inner notch 8 in the supporting lamination cooperating with a collar 7 on the central hub 15. As shown in Fig. 3, the sector is completed by a stack of unwelded laminations of the same size as the supporting lamination and by the supporting lamination of the following sector. Each sector is then welded to the hub 15 as at 14. When the entire core is assembled an outer ring 6 is placed in the outer notches 8 and an insulating tube 17 is then placed around the edges of the circumferential edge of the core 0. This tube 17 is held in place by a screw 22 threaded into the ring 6.

The core assembly thus forms a rigid assembly utilizing radial laminations but in which no additional eddy current path is formed because of the welded structure. Inasmuch as the welds are

SPECIFICATION of patent cited in Plate A is a written description of the invention. It is written in such clear and exact terms that any person skilled in the field of the invention can make it or use it without difficulty. **(PLATE B)**

A typical U. S. patent, chosen for the purpose of explaining the make-up of a patent, is No. 2,468,786.[4] This particular patent comprises one sheet of drawing and three pages of printed matter. The sheet of drawing is shown in Plate A. The first page of the printed matter is shown in Plate B. The printed matter is known as the specification. When received from the U. S. Patent Office, the pages are stapled together so that the patent has the appearance of a booklet, roughly of letter size.

Patent heading contains useful information

The first page of the specification, illustrated in Plate B, carries information at the top of the page which permits identification and classification of the patent. In the upper left-hand corner appear the words, Patented May 3, 1949. This is the issue

[4] The reader is advised to obtain a copy of this patent. It is only by studying the patent copy first-hand that the reader will appreciate the points brought out in this article. Patent copies cost 25 cents and are obtainable from the Commissioner of Patents, Washington 25, D. C. When ordering, give identifying number, name of inventor, and date of issue.

date of the patent. Without looking at a calendar for 1949 we know that May 3, 1949 was a Tuesday because it is only on Tuesdays that patents issue. Since U. S. patents have a life of 17 years, the patent will be in force until May 3, 1966. In the upper right-hand corner appears the patent number, 2,468,786. This identifies the patent as the 2,468,786th patent to issue since the Patent Office began numbering patents in 1836.[5] Before that date, patents were not numbered serially. Next in bold face type appears the government office of origin, the UNITED STATES PATENT OFFICE. Beneath it, in small type, the patent number is repeated. Under the number is printed the title of the patent, ELECTROMAGNETIC CORE ASSEMBLY AND METHOD.

Below the title, a brief paragraph in block form gives the names of the inventors and their post office address. This paragraph also contains the further information that the patent has been assigned to the Allis-Chalmers Manufacturing Company, a corporation of Delaware. This latter statement means that Allis-Chalmers was the owner of the patent when it issued.

Next appears the date when the patent application was filed in the United States Patent Office, August 21, 1944, and the serial number of the application. The filing date, August 21, 1944, is important because a United States Patent is a reference for what it discloses as of its filing date. Beneath the filing date appears the statement, "6 claims," which means there are six formal definitions of the invention at the end of the specification.

To the right of the statement, "6 claims," there appears in parentheses the expression, "Cl. 175-356." This simply means that, at the time of issue, the patent was classified by the U. S. Patent Office in Patent Office Class 175, Subclass 356. If one refers to the looseleaf classification manual issued by the Patent Office, he will find that Class 175 is identified as Electricity, General Applications, and Subclass 356 as Stationary Induction Apparatus. This method of classifying patents was adopted by the Patent Office to enable a searcher to find similar patents relating to the same subject matter. Thus there are today roughly 50,000 classes and subclasses into which all U. S. patents are respectively classified. These classes and subclasses are constantly being revised by the Patent Office.

First paragraph of patent orients reader

The printed matter below the heading is known as the specification. For convenience of discussion, it may be thought of as divided into a number of parts which are identified as —

Statement of Invention
Discussion of Prior Art
Objects of Invention
List of the Drawings
Description of Embodiments Shown in Drawings
Claims

The opening paragraph of the specification (page 1 of the patent) is known as the statement of invention. Its purpose is to point out to the reader the field of art in which the invention lies. Its significance lies in the fact that, if it is not carefully stated, it may unnecessarily limit the protection afforded by the patent claims at the end of the specification.

The patent copy of Plate B, in the first paragraph on page 1, discloses that the invention relates in general to electromagnetic cores. The statement of invention further informs the reader that the kind of core referred to is an improved core assembly for induction apparatus. And the statement identifies the particular type of core as one that has substantially radial laminations. Lastly, the statement of invention informs the reader that the invention also relates to an improved method of assembling such a core.

Following the opening paragraph, the patent generally discusses the prior art. By the term "prior art" is meant those inventions and practices which have already been utilized by others in the past.

The patent copy of Plate B follows the accepted practice and states that the laminations of prior art cores were held together during assembly of the core by thermosetting varnish. The patent goes on to state that the varnish has the disadvantage of permitting the laminations to move relative to one another during assembly and operation. This disadvantage, the patent discloses in its third paragraph, has been overcome by the present invention.

Following the discussion of the prior art, the patent proceeds to state the purposes of the invention. The statements of these purposes are known as the objects of invention. They are important because they are often examined by the courts when patent claims are in dispute to determine the inventor's exact intentions. The objects of invention tell what the invention seeks to accomplish.

Directly following the objects of invention is a brief list of the figures of the drawing. These figures illustrate certain embodiments of the invention. Following the list of figures of the drawing is a detailed description of the embodiments shown in the drawings.

In the description, the figures of the drawings are referred to and the various elements shown in the drawings are identified by reference numerals. For example, in Figure 3 of the patent drawings the laminations of the core are identified by the reference numeral 5. The description of the invention is required by law to be so clear that any person skilled in the field to which the invention pertains can make it when the patent expires.

Patent claims define the invention

The patent specification ends with one or more claims, which are formal definitions of the invention. To the casual reader, patent claims offer the most difficulties. In form, each claim comprises a single sentence. Since it is not unusual for claims to number 200 words or more, it is easy to see why they are difficult to read. The engineer may ask if anything can be done about the length of patent claims. Short of reforming the Patent Office and the patent attorneys, the answer is no. The form of the patent claim, while relatively new historically, has become established through long usage. There is little likelihood of any immediate change. There is no recourse, then, except for the engineer to relax, even if he can't enjoy it.

One other characteristic of the patent claim which baffles the novice is the language used. Patent attorneys, like members of all professions, employ a professional jargon. It is not employed, however, to mystify engineers, as many of them seem to think, but rather because the jargon has over a period of years acquired a legal certainty. It must be remembered that patent claims are definitions of the invention. Since they distinguish the inventor's contribution from all others, they must be stated with an exactness that will withstand the scrutiny of the courts during the life of the patent. Through court and Patent Office decisions, certain terms used in claims

[5] Barring those patents that have been withdrawn from issue by the Patent Office for various reasons.

1. A core assembly of laminations of sheet metal extending substantially radially about a longitudinal axis, said core assembly comprising a plurality of sectors, certain of said sectors comprising a plurality of stacked packages of said laminations, adjacent said packages being non-uniformly spaced from said axis to define a series of steps, each said package comprising a stack of laminations which are at a substantially uniform distance from said axis and a single lamination extending to a smaller distance from said axis to define a protruding edge, said protruding edges lying substantially parallel to said axis, said edges resting on a common supporting lamination of an adjacent said sector, and bonds of fused metal uniting certain of said packages with said supporting lamination at intermediate points of the lines of contact of said edges with said supporting lamination.

Patent Claim No. 1

Defines the Invention

List of Prior Art cited by the Patent office during the Prosecution of this Patent

THE CLAIM, shown above, defines the invention protected by the patent. It must distinguish the invention from all other inventions known to the public. **(PLATE C)**

REFERENCES CITED

The following references are of record in the file of this patent:

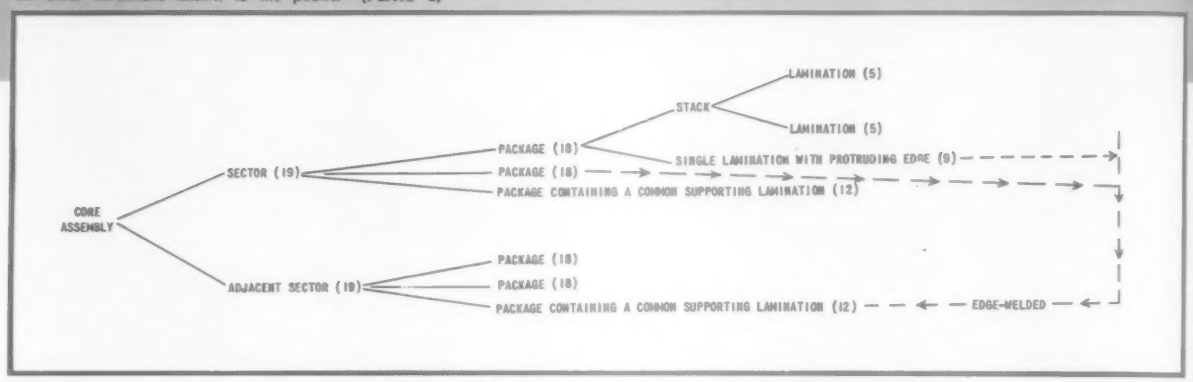
UNITED STATES PATENTS

Number	Name	Date
2,114,070	Bouwers	Apr. 12, 1938
2,359,102	Foster	Sept. 26, 1944

FOREIGN PATENTS

Number	Country	Date
27,873	Sweden	Aug. 8, 1908
111,716	Germany	July 9, 1900
482,771	Great Britain	Apr. 5, 1938
504,328	France	Apr. 12, 1920
595,363	France	July 13, 1925

PRIOR ART REFERENCES cited against the application for U. S. Pa... No. 2,468,786 while it was pending in the United States Patent Of... are listed above. These references, found at the end of the specifica... do not disclose the invention claimed in the patent. **(PLATE E)**



GRAPH OF CLAIM 1 of U. S. Patent No. 2,468,786, shown in Plate C, illustrates one way to analyze a claim so that the invention it describes may be more easily detected. Graphing may help in future readings. **(PLATE D)**

have come to have a precise meaning. It will be well for the engineer to become acquainted with the meanings of the more common of these terms. Expressions like "comprising," "consisting," "plurality," "substantially," "predetermined," and "means for" doing so and so appear frequently in claim language.[6]

Patent claims make sense

When reading a patent claim, the engineer should always remember that he is simply reading a definition of the invention. If this is kept in mind, the claim will be more easily understood as the reading proceeds. For explanatory purposes, claim 1 of the patent will be discussed, see Plate C.

A count of the number of words in claim 1 shows the claim to contain 137 words. There is no doubt that, while this number of words makes the claim very difficult to read, it does not follow that it makes it impossible to read. Before attempting to analyze the claim, however, the engineer should ask himself "What do I already know about the invention?" If the engineer has read the first paragraph on page 1 of the patent copy, i.e., the statement of invention, he knows that the invention has to do with the electromagnetic core of a piece of induction apparatus. He knows further that the invention deals with a core which has substantially radial laminations. He is probably familiar with laminated cores and by looking at the drawings and briefly reading the description he should have a good idea of the structure described. With this in mind, he is ready to undertake reading of the claims. The engineer will probably find it helpful in tackling his first few claims to list the elements recited and identify them from the drawings by reference numerals. If he uses this method with claim 1, he will have the following list of elements:

Elements	*Reference Character*	*Drawing*
Core Assembly		Fig. 1
Laminations	5	Figs. 3 and 4
Packages of Laminations	18	Fig. 3
	28	Fig. 4
Common Supporting Lamination	12	Figs. 3 and 4
Single Lamination	9	Fig. 3
	29	Fig. 4
Protruding Edge of Lamination	11	Figs. 3 and 4
Bonds of Fused Metal	11	Figs. 3 and 4

Understanding the claim

If the claim is again examined, keeping in mind the listed elements, the engineer will see that the claim is merely a recitation of those elements linked together by functional language to define an operative structure. The functional language of claim 1 explains how the laminations are arranged to form a stack, how the stack is combined with a single lamination of longer length to form a package, how the packages are arranged to define a series of steps, how a group of these stepped pack-

[6] These terms have a precise meaning when used in patent claims. "Comprising" leaves a claim open for the inclusion of unspecified elements. In other words, "comprising" does not exclude elements which are not recited. "Consisting of" closes the claim to the inclusion of elements other than those recited. "Predetermined" means measured beforehand or preselected. "Plurality" as a modifier means more than one. "Substantially" implies permissibility of a slight latitude or variation. "Means for" doing so and so is the broadest way of defining an element. For example, "means for supplying power to a driven shaft" could be any one, or combination, of several sources of motive power, such as an electric motor, gas turbine, or diesel engine.

ages form a sector and how each sector is bonded by an edge weld to a supporting lamination of the next adjacent sector to result in a core assembly. The engineer will note the recurring use of the term "plurality" which simply means more than one. Thus, a core assembly comprising a plurality of sectors comprises more than one sector. By this time the engineer will have already discovered that the recitation of elements in the claim is according to a descending order of magnitude of the elements, but this is not always so. For example, the core assembly generally comprises sectors, each sector in turn comprises packages, each package in turn comprises a stack of laminations together with a single lamination having a protruding edge. A simple graph of the claim would look like that shown in Plate D when read on Figure 3 of the patent drawings.

Such a graph is the first step in understanding the claim, and it can be made to show the invention defined by the claim. Here the invention comprises the edge welding of the protruding edges of the packages to the common supporting lamination of the next adjacent sector.

The engineer will find it wise to keep his graph as simple as possible. Complicated graphs can be more difficult to understand than the bare claim itself. The experience gained by graphing will eventually enable the engineer to discard the graph in favor of a shorthand statement of the claim. For example, claim 1 can be reduced to a statement, "packages of laminations having their protruding edges edge-welded to a supporting lamination of the adjacent sector." Or shorter yet, "packages protrudingly edge-welded to adjacent sector." Some engineers may find it helpful to use symbolic notation to indicate the contents of the claim, such as ABC, ABD, etc., where the letters stand for the elements listed.

Once the engineer recognizes the invention defined by the first claim, he is ready to examine the second claim. The procedure will be the same. Listing the elements and comparing the list with that for claim 1, the engineer will discover that claim 2 mentions for the first time another element; namely, "a central member." (See line 59 of column 3 of the patent.) Claim 2 further states that another bond of fused metal unites the supporting lamination with the central member. (See lines 1-2, column 4 of the patent.) These are features not mentioned in claim 1 and serve to distinguish claim 2 from claim 1.

The graph for claim 2 will be similar to the graph for claim 1 with the addition of the "central member" and an added broken line showing the welding of the supporting lamination to the central member. Using the shorthand method claim 2 can be represented by "claim 1 plus supporting lamination welded to central member."

The remaining claims can be treated in like fashion and a simple table drawn up distinguishing the claims from one another. When this is done, the engineer is in a position to see whether the claims read on (i.e. define) the particular device he is interested in, which device may be his company's proposed product.

Engineer can help avoid infringement

The ability to analyze claims is an important one for the engineer. He, more than anyone else, is in a position to prevent his company from infringing another's patents. By infringing is meant using another's patented invention without the owner's permission. If the engineer is familiar with the prior art and his competitor's patents, he is well able to protect his company from possible liability arising out of infringement. Such liability may take the form of a money settlement with the owner of the infringed patent. It may mean the scrapping of costly tools and dies through a forced change in design. Or it may mean the expense of defending a lawsuit and the payment of damages if his company is the loser. Generally this responsibility falls on the shoulders of the chief engineers of corporate organizations. Usually they delegate it to one of their subordinates. Since any engineer may suddenly have the responsibility thrust upon him, it is not a bad idea for the young engineer to become familiar with patents early in his career. The earlier the better, because he will find that patent knowledge is predominately gained by experience and not from textbooks.

The engineer, reading a recently issued patent, such as U. S. 2,468,786, will notice that the patent copy carries at the end of the specification a paragraph entitled, "References Cited," Plate E. The references referred to are usually United States and foreign patents, but may include magazine articles and textbooks. They comprise the prior art which the Patent Examiner in the U. S. Patent Office cited against the patent application during its prosecution. This art is of value in determining the scope of the patent claim. The term "scope" in patent law has the usual dictionary definition: namely, range and extent. When applied to a patent claim, it means the range and extent of the invention defined by the claim. Thus a claim concerning vacuum tubes, when read literally, might appear to cover all types of vacuum tubes, yet when read in view of the cited prior art may be limited to screen grid tubes.

Knowledge of the prior art in his own particular field is of inestimable value to the engineer because he can rapidly assess the value of a patent by means of such knowledge. Occasionally the Patent Office, through inadvertence or mistake, issues a patent containing one or more claims of doubtful validity. If the engineer has a good knowledge of the prior art, he is in a position to detect such spurious claims and provide his company with the basis for a good defense against any possible charges of infringement.

Besides the ability to recognize infringement, a knowledge of the prior art will aid the engineer in recognizing a patentable invention when he sees one. This follows when it is understood that an invention to be patentable must be a measurable advance over the prior art. Without a knowledge of the prior art, it is therefore impossible to say whether an invention is patentable or not.

It is therefore to the engineer's advantage to acquire a certain competence in the field of patents. A working knowledge of patents can be obtained only through actual experience and by reading relevant material dealing with patents and their need in engineering. The sources of information on this subject are many and readily available. A short bibliography of works written to enable engineers to arrive at a clearer understanding of patents appears at the end of this article.

BIBLIOGRAPHY

Patent Background for Engineers issued by Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin. 1941.

Patent Notes for Engineers by C. D. Tuska, RCA Review, Princeton, N. J. 1947. 165 p.

Use of Technical Library by R. H. Whitford and J. B. O'Farrell, Mechanical Engineering, December 1948. p. 987. (See "Patents," p. 991.)

Inventions and Their Management by Alf. K. Berle and L. Sprague DeCamp, International Textbook Co., Scranton, Pa., 2nd ed. 1947. 742 p. (Cites an Allis-Chalmers patent on pages 243-249.)

Basic U. S. Inventions issued by Allis-Chalmers Manufacturing Company, Milwaukee, Wis. 1944. 31 p.

Repainting Transformers IN THE FIELD

by J. R. MANN
Transformer Section
Allis-Chalmers Mfg. Co.

and

O. V. STEWART
Vice-President
James B. Sipe Co.
Pittsburgh, Pa.

FLOW-COAT PAINTING in the field is fast and economical, requiring minimum equipment and no special skill. All that is needed is a catch basin for paint, a pump to recirculate and hose to apply it. Equipment is inexpensive and easy to set up.

Modern methods simplify painting and assure maximum protection and eye appeal . . . and the best job is still the cheapest. Authors tell what to do, when to do it, and how.

TRANSFORMERS have been discussed at length in literally hundreds of papers, articles, and books since their first commercial use in 1884. Nearly every subject from drain valves to hot-spot temperature rise has been included, with the majority of information being concerned with internal electrical and thermal matters. There is, however, an everyday problem confronting all manufacturers and users of transformers which has received very little literary attention. That is the problem of external protection of the equipment.

Since the average life of any good transformer far exceeds the life of the paint which protects it, users are confronted with the task of repainting in the field. Nearly every utility company has set up painting programs, but the methods of preparing the surfaces, the types of paint used, and the means of applying the paint vary widely from one company to the next. Modern painting practices used by manufacturers and utilities reveal how some of the faults encountered can be eliminated and economies effected.

Use influences paint choice

Much of the unnecessary painting costs confronting utilities can be reduced considerably by the transformer manufacturer if proper painting materials, equipment, and methods are used.

If the manufacturer doesn't do a proper job in the factory, the utility is bound to have a premature problem. The factory chemist, or design engineer, must choose the right materials. His choice depends not only upon the quality of the products on the market but also upon the facilities that are available in his shops for applying them.

First, he must know the operating conditions under which the transformer will be used. Most transformers operate out of doors and are subject to the elements 365 days a year. They may have to withstand the extreme heat and humidity of the tropics, or the severe winters of the north land which subject equipment to operating temperature ranges from —30 degrees F to 230 degrees F or more at overloads. Or, transformers may be exposed to salt water and salt water vapors along the seashores or extreme dampness in marshy areas. They may be located near factories where air is contaminated with smoke and acid fumes, or adjacent to generating stations where fly ash is allowed to settle on equipment. Most of the units will be oil-filled, so the possibility of oil leaking on the tank must be considered. In other words, the paint must stand considerable abuse.

Perhaps the most important requirement for a successful paint job is proper surface preparation. Paint of any type works best on a clean surface that is not too smooth. Hence, large transformer tanks should be shot-blasted and smaller units can be either shot-blasted or etched by phosphatizing.[1] Paint should never be applied over rust, oil, or other dirt; hence, surface cleaning should be done just prior to the application of the first coat.

Knowing the conditions in which transformers operate, the chemist or engineer can select either of two general classes of

[1] Dipping the tanks in a solution of phosphoric acid and other salts results in a coat of phosphate of iron forming over the surfaces which in itself is a mild inhibitor against corrosion. The primary purpose of phosphatizing, however, is to get a firm anchor for the first coat of paint by etching the steel surface. Automobile fenders, for example, are treated in this manner before painting.

paints — namely, synthetic or long oil types. The latter is also known as oleoresinous or varnish type.

The pigmentation of both types is the same; the difference being in the vehicle. Usually, the vehicle of synthetic paint is a resin of the glycerol phthalic type, which may be modified by other similar synthetic resins. The vehicle of the long oil paint, on the other hand, is a combination of heat-treated and re-inforced vegetable oils.

Synthetic paints preferred

Both of these types are being used today, although most manufacturers have adopted the synthetic paints as standard. They are readily adaptable to manufacturing methods and provide excellent color and gloss retention. Although they will air dry, better results are obtained when synthetic paints are baked. The baking operation changes the molecular structure, resulting in a denser and more homogeneous paint film. Baking also expedites drying time and production.

Assuming that the class of paint has been chosen, which manufactured product shall the chemist or engineer buy? The obvious answer is to try several under test conditions before making a decision. Unfortunately, this is not an overnight task. Using the best laboratory instruments available, it takes at least six months to separate good from bad, and closer to three years to find the best one. Evidently, there would be a good deal of duplicated effort if each utility company went through this lengthy process. Consequently, the best and quickest solution would be to contact the transformer manufacturer or a reputable paint manufacturer specializing in transformer paints who should have the necessary data available.

The proper paint is now chosen, but how many coats should be applied, and what is the difference between these coats? The general rule that the thicker the layer the better the protection is a good one — provided, of course, that proper adhesion is obtained.

Common practice in painting pole type or small distribution transformers is to phosphatize the tank, then apply a coat of primer and a coat of finish paint, both coats being baked. Just prior to shipment the completed transformer may be given a light coat of finish paint, air-dried, to provide good appearance. Large power transformers are usually painted with an engineered three-coat system.

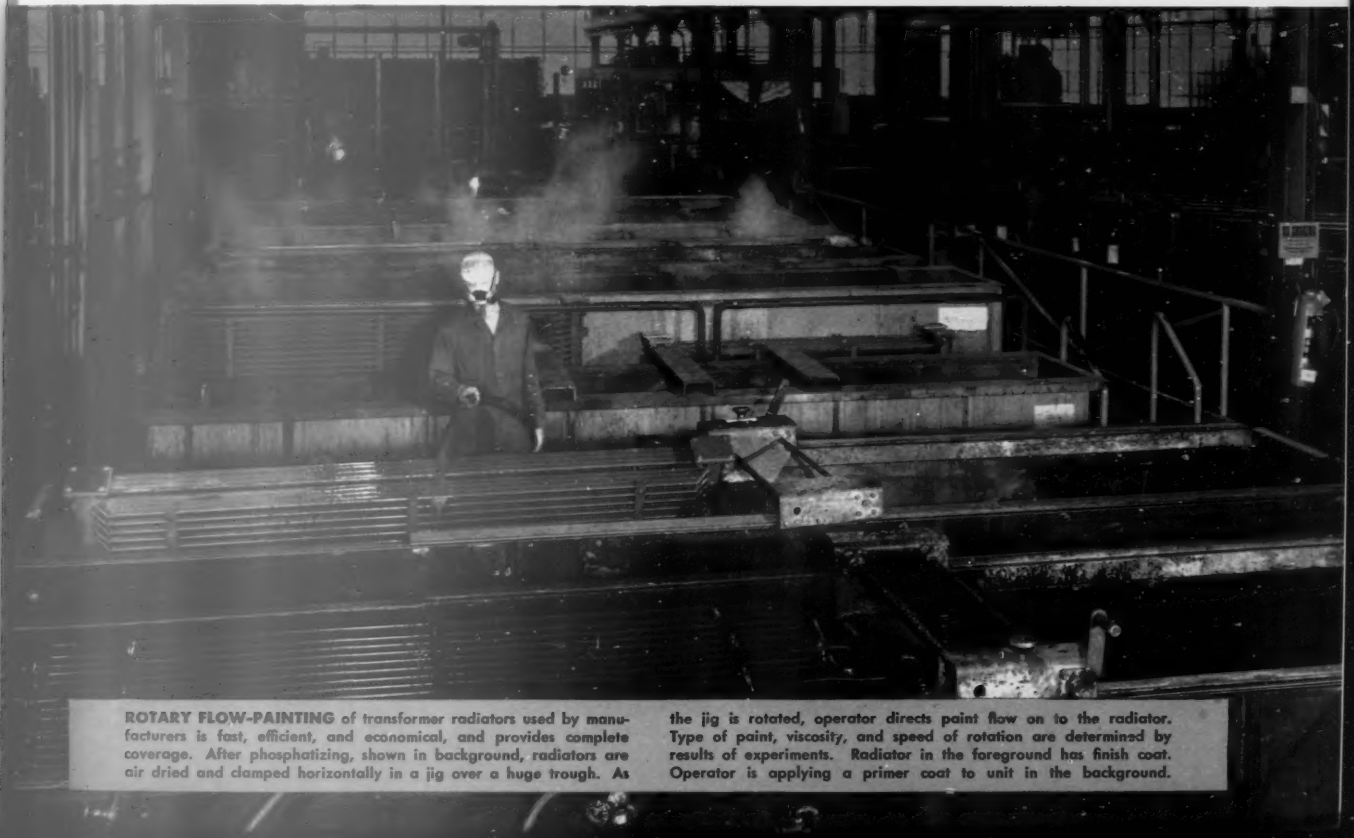
The primer coat is formulated to provide good adhesion to bare metal, low gloss to insure good adhesion of the second coat, and contains corrosion-resisting pigments to retard the formation and spread of corrosion. The second, or body coat, is designed to provide a good bond between the primer and finish coats. The finish coat contains the proper materials to provide maximum resistance to the elements, combined with a lasting ornate appearance.

Each coat is of a different color to assure complete coverage by identification. It is best to use paints manufactured by the same supplier for all coats, because there is greater likelihood that they will be compatible.

Final color is affected by two primary considerations — appearance, and heat transfer ability. Light colors, such as white, grey, or aluminum, reflect heat from the sun better than a dark color. However, they also hold generated heat inside the tank and radiator and retard cooling. The net effect of using light colors is always negative; operating temperatures are invariably higher. For this reason, when light-colored paint is specified the transformer manufacturers make heat runs before applying the paint.

Three painting methods used

Enough of the preliminaries; let's paint the transformer. There is a choice of three methods of getting the paint onto the various metal parts — by brush, spray gun, or flow-coating. Each is satisfactory for certain uses.



ROTARY FLOW-PAINTING of transformer radiators used by manufacturers is fast, efficient, and economical, and provides complete coverage. After phosphatizing, shown in background, radiators are air dried and clamped horizontally in a jig over a huge trough. As the jig is rotated, operator directs paint flow on to the radiator. Type of paint, viscosity, and speed of rotation are determined by results of experiments. Radiator in the foreground has finish coat. Operator is applying a primer coat to unit in the background.

Brushing has the obvious disadvantage of being costly, but most "touch-up" work and inside control cabinet finishing is done in this manner. Good coverage and even thickness can be obtained, but since it is a time-consuming procedure it is rarely economically justified for large areas.

The biggest portion of factory painting is done with a spray gun. It is a quick and effective method that requires some skill, but it is not too difficult. Spraying requires special equipment to protect the painters and other workers in the vicinity from breathing the paint particles in suspension; so the initial expenditures are quite high. However, in factories, where large numbers of transformers are painted, this cost can be returned by the saving in labor.

Some transformer parts, such as radiators, offer a real challenge to the painter. The complex structures defy the ability of a brush or spray gun to get adequate coverage over all of the hidden parts. Best results for these pieces are obtained by the flow-coat method. As the name implies, this process consists of pouring paint over the object and allowing it to run onto the remote surfaces. Flow-coating is done easily by pumping the paint through an open nozzle, collecting the excess liquid beneath the work, and returning it to the supply tank for recirculation. This method requires little skill, but a very careful control of the paint viscosity must be maintained to obtain the proper finish. If the paint is too thick it will sag and "curtain." If it is too thin proper protection will not be obtained.

When the transformer leaves the factory it has a protecting surface that should give five to eight years of service without attention. That, of course, will depend upon the atmospheric conditions, but this figure is a good average throughout the United States. The paint should "chalk" with age, not check or peel; so that refinishing can be done at minimum cost.

Obviously, the time to refinish a unit is before any rusting of the protected surface occurs. Appearance may be a deciding factor, but chances are that several years of good protection are left after the original color has been covered with a dust and oxide film. However, if the job is put off too long the need of extra expense in preparing the surfaces for painting may arise.

Delays may prove costly

A simple brushing to remove dirt is all that is necessary when the paint has merely chalked. If there are a few rust spots, these should be wire-brushed and spot-primed before proceeding further. All loose and scaly paint should be removed by scraping and wire brushing. Oil and grease can be washed off with petroleum naphtha.

Many transformers in service are neglected until the only satisfactory method of preparing the surfaces for repainting is to remove all of the old paint. Until recently, this was a tremendous problem and many utilities did any kind of a "patch-up" job rather than go to such expense. However, today the same flow-coat method can be applied here as is used in factory painting of radiators. The results reported are excellent.[2]

Stripping is done by flowing a hot (175 degrees F) solution of caustic alkali plus a wetting agent over the transformer. This is washed off with a weak solution of phosphoric acid at 190 degrees F, followed by a clean water rinse. If done properly, every bit of paint can be removed.

[2] *Corrosion Protection of Power Transformers by Flow-Coat Method*, by Siebert L. Miller, *Corrosion*, May, 1950.

TRANSFORMER RADIATORS 18 feet long can be handled easily by the flow-coat paint method. After paint has set, radiator is hoisted into an oven in which hot air circulates and exhausts in short cycles and bakes paint dry. Jet was turned on just before photo was taken.

Repainting in the field is done by the same three methods described for factory work; that is, brushing, spraying, or flow-coating. The first two need no further description, but the latter method has some definite peculiarities when done in the field. It is, of course, necessary to catch the excess paint and recirculate it through the system. This requires a number of catch basins (usually sheet metal), which must be fitted around the base of the transformer. Some utilities, using a solid cement mounting pad, put a timber barrier around the sides and let the paint collect directly on the pad. It is then scooped into the return pump, and very little preparation work is necessary. Although the flow-coat method seems difficult, it is actually the cheapest, quickest, and best method where a complete repainting is necessary. No other method of application will give assurance of a full and complete film of paint on inaccessible places, such as backs of radiator tubes.

Thus, like the working parts of the transformer, paint is also carefully selected to provide maximum protection and eye-appeal under particular operating conditions. This initial selection eliminates frequently expensive 'guesswork on the part of the user regarding the most practical and economical method of painting a transformer in the field. Type of surface preparation and paint, as well as the reasons for it, can be obtained from the manufacturer for future guidance. The methods of applying paint can also be learned from the manufacturer to effect additional savings in this important but commonly overlooked preventive maintenance problem.

the BETATRON today

Part Two of Two Parts

Design, construction, and control circuits of the betatron reflect the fusing of engineering and science for the advancement of science, medicine, and industry.

by R. C. ODELL
Betatron Group
Transformer Section
Allis-Chalmers Mfg. Co.

DISCUSSION OF THE BASIC THEORY of the betatron up to this point indicates several engineering problems of unusual interest. These problems will be discussed as they occur in the description of the electrical circuits and construction of the betatron unit.

First, there is the problem of a supply of suitable exciting frequency for the magnet core. Commercial frequencies of 60 cycles could be used, but by putting to work the usually suppressed third harmonic in transformer magnetization several advantages are gained. Another problem arises from the fact that the large air gap necessary in the core requires about 20,000-ampere turns to force the flux across it. An apparent power of 2500 kva at a power factor of less than one percent lagging is necessary to supply this excitation. Power under these conditions would be impossible to obtain commercially (and impractical to obtain otherwise) so a novel arrangement of resonating capacitors with the magnet-exciting winding is employed. A third problem, the time of firing electronic control circuits, must be accurately synchronized with the rate of rise of the flux in the magnet. Time differentials in the order of microseconds are accomplished, using a peaking transformer which employs a thin strip of high permeability steel having an extremely sharp knee and high saturation point. A fourth problem arises because the eddy current loss in the core steel must be far below the minimum established for a transformer core of equivalent size, otherwise X-ray yields of usable amounts cannot be obtained.

Power supply uses third harmonic

It is, of course, a requirement that the X-ray yield from the betatron be high, otherwise the machine would be of no practical value regardless of its energy. Since a burst of X-rays (see Part 1, Figure 2a) occurs once every cycle, it is advantageous to have as many cycles per second as is practical. A frequency of 180 cycles per second was chosen for these reasons:

(1) It provides three times as many X-ray bursts per second as a 60-cycle machine would.

(2) A static type frequency converter for 180 cycles from a 60-cycle source can be obtained at low cost.

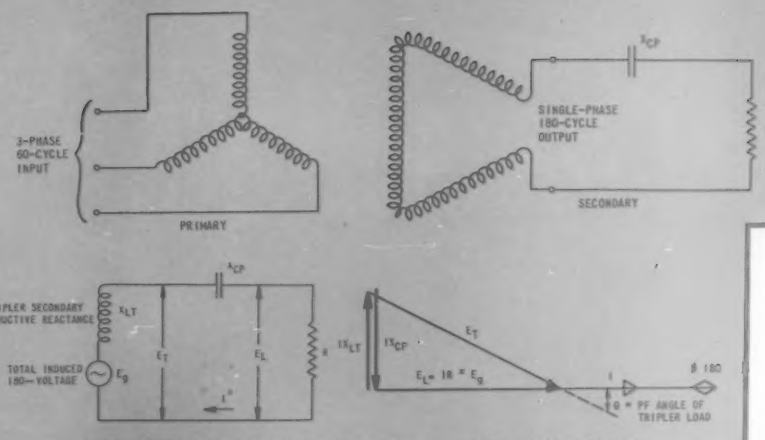
(3) Although a betatron can be designed to operate with 60-cycle excitation, a higher frequency provides a larger rate of change of flux, $\frac{d\phi}{dt}$, which provides enough damping forces for better control of the electron beam.

(4) Operation at frequencies higher than 180 cycles is possible too, but this frequency is the most desirable because of the increased cost in the power supply for higher frequencies, the complexity of magnet cooling and other subtle problems such as high eddy current fields at the time of injection.

The static power supply for 180 cycles per second is of unusual interest because it makes use of the non-linearity of the saturation curve in the generation of third harmonic voltages. Of course, a rotating type power supply could be used but it is high in first cost and requires maintenance. Furthermore, its voltage stability as a function of line frequency variation is not good, nor is it good under varying betatron load.

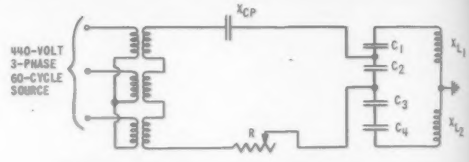
The static supply consists of three single-phase transformers (called triplers) operated at very high flux densities. In normal practice the designer of electrical machines keeps the densities low enough to avoid troublesome harmonics that might appear in the current or voltage waves. Otherwise telephone interference, excessive dielectric stresses, and other troublesome conditions will occur. However, in the design of tripler transformers the flux density in the core of each unit is of the order of 21,000 gausses instead of the 11,000 to 13,000 gausses normally employed. Since the cores are operated above the knee of the saturation curve the third harmonic component is very high. At 21,000 gausses it is in the order of 60 percent of the fundamental.

In single-phase transformers the flux wave is the same shape as the primary voltage and the harmonics will appear in the primary current. But if three transformers are connected in wye-delta and excited from a three-phase line with the neutral isolated a third harmonic current cannot flow because a return path does not exist. The only place left for the harmonic to exist is in the phase voltages since it cannot appear from line to line. Therefore, a third harmonic flux will exist in the core which will induce a third harmonic voltage in the secondary. If the delta remains closed, the third harmonic voltages will circulate a third harmonic current and the fundamental or 60-cycle voltage would appear from line to line. But if the delta is opened, the fundamental voltages will cancel and the third harmonics will add. Across the open delta connection one will measure a voltage three times as great as the 180-cycle voltage appearing across each secondary. This voltage contains a slight percentage of ninth and fifteenth harmonics so that the shape of the 180-cycle wave is not quite a sine wave. The primary line current will contain prominent fifth, seventh, and higher harmonics but no third or higher multiples of the third.



TRIPLER TRANSFORMER with tuning capacitor in output side for improvement of secondary voltage regulation. **(FIGURE 5a)**

SCHEMATIC DIAGRAM shown above is a representation of the tripler circuit of Figure 5a. Its vector diagram is shown at right. **(FIGURE 5b)**



POWER CIRCUIT of the 24-million-volt betatron is shown schematically. The magnet core of this unit is represented by inductances X_{L_2} and X_{L_1}. **(FIGURE 6)**

By judicious design of the core and coils, the induced third harmonic voltage may be as high as 62 percent of the 60-cycle voltage induced in the secondary winding. If flux densities are increased too far above the knee of the saturation curve, where practically a straight line function is encountered, the third harmonics generated would be negligible. Thus, for a particular quality of steel there is an optimum point where the maximum third harmonic is generated.

Two important considerations are the input power factor and the secondary voltage regulation. The iron in the tripler is saturated during a considerable portion of the cycle, resulting in a low excitation reactance. Under load a 180-cycle flux is produced in the core by the output load current (since no 180-cycle current can flow in the primary to balance this load current) and the voltage induced by this flux behaves like a leakage reactance drop of a normal transformer. Since this 180-cycle flux exists almost entirely in a low reluctance iron path (rather than the leakage path in air of a normal transformer) the secondary reactance of the tripler assembly will be several times greater than the reactance of a normal transformer bank of equivalent size.

Because of the low excitation reactance and high secondary reactance, the input power factor is very low and the voltage regulation poor. However, it is possible to raise the power factor from its normal of about 30 percent to about 50 percent by the use of capacitors in the primary circuit. Higher correction is hindered by the presence of fifth and seventh harmonics in the input current. Much depends upon the particular installation conditions whether any correction is actually necessary. Since the total betatron requirement is only 100 kva, most power companies have not required that correction be made. Voltage regulation can be improved greatly by adding a series capacitor to the tripler output. If the capacitive reactance is made numerically equal to the tripler secondary reactance, the resultant power output is limited only by the losses in the system and the percent voltage regulation is zero.

Figures 5a and 5b show the tripler circuit and vector diagram for a resistive load. Since X_{CP} is made equal to X_{LT} the voltage regulation indicated is zero. Actually, X_{LT} is only approximately constant with changes in load current since the 180-cycle flux producing IX_{LT} exists principally in the iron, and hence is subject to the varying permeability of the iron core. However, X_{LT} is fairly constant since the iron is saturated for a considerable portion of the cycle and the 180-cycle flux is superimposed on top of that, thus providing little permeability change. As a practical result of this, the voltage regulation is very good over the entire operating range.

The tripler transformers feed into a series resistance and a parallel resonant circuit (Figure 6). The series resistance may be tapped in and out of the circuit at will, thereby providing a means of varying the peak energy output of the betatron. As resistance is increased or decreased in the circuit, the voltage across the resonant circuit decreases or increases. Thus the voltage applied to the magnet-exciting coils varies in a like manner, limiting the peak magnetic flux thru which the electron stream can be accelerated.

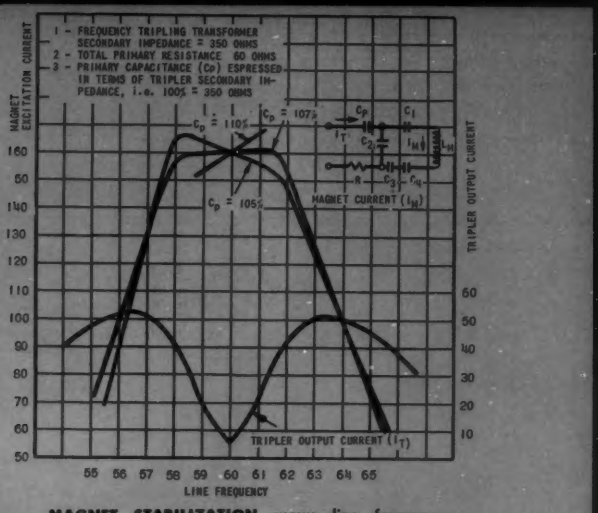
The resonant circuit supplies the magnetizing kva for the magnet. In such a circuit the power furnished from the line is needed only to supply the losses. During part of the cycle the energy stored in the capacitor supplies the magnet excitation and during the other half the capacitors are recharged by the energy given up by the collapsing magnetic field. The exciting kva oscillates from magnet to capacitor bank and back again. Another advantage of this system is that voltages across component parts may be kept at reasonable values consistent with economical design practice. The potential across each air-cooled magnet coil is about 7,000 volts and that across the air-cooled capacitors about 3,500 volts. The capacitor cubicle is shown in Figure 7.

Circuit parameters critical

An important consideration in choosing the values of the parameters of the power circuit is apparent when it is realized that tuned circuits of resistances, capacitors, and iron core magnetic circuits depend upon constancy of line frequency and voltage and negligible temperature coefficients to remain in tune. Otherwise, the voltages across the inductive and capacitive components will vary widely and affect the output energy of the machine. Since the yield in X-rays varies at about 3.3 power of the energy, a constant magnet core-exciting voltage is mandatory. Another effect is that the resultant circuit unbalance will increase kva requirements from the line and trip overload breakers.

A large amount of laborious calculations were required to determine the proper values for the circuit resistance, capacitance, and tripler secondary reactance that would provide a minimum change in magnet-exciting current with the frequency variations occurring in commercially available power.

CAPACITOR CUBICLE shown being assembled in the shop contains about sixty 42-kva capacitors. Cubicle can be set remote from the betatron near the power source. **(FIGURE 7)**


1 - FREQUENCY TRIPLING TRANSFORMER SECONDARY IMPEDANCE = 350 OHMS
2 - TOTAL PRIMARY RESISTANCE 60 OHMS
3 - PRIMARY CAPACITANCE (Cp) EXPRESSED IN TERMS OF TRIPLER SECONDARY IMPEDANCE, i.e. 100% = 350 OHMS
MAGNET EXCITATION CURRENT
TRIPLER OUTPUT CURRENT
Cp = 107%
Cp = 110%
Cp = 105%
MAGNET CURRENT (IM)
TRIPLER OUTPUT CURRENT (IT)
LINE FREQUENCY

MAGNET STABILIZATION versus line frequency change. Curves show how well magnet current can be held independent of normal frequency change. **(FIG. 8)**

Subsequent tests at one installation, where frequency could be varied at will, proved the accuracy of these calculations with results lying almost perfectly upon the calculated flat-topped characteristic curve.

Figure 8 shows the magnet-exciting current response as a function of frequency for typical circuit constants used with the 24-million-volt betatron. Note that the best condition is reached when the tripler tuning capacitor actually has a capacitance greater than that required to balance out the tripler third harmonic impedance. Since the actual spread of commercial frequencies is seldom greater than 59.5 to 60.5 cycles, and is usually within half this difference, the magnet amplitude — and hence the yield — is quite steady.

Line voltage variations up to four percent can be tolerated since the tripler transformers operate most of each cycle in a saturated condition. Voltage variations affect the permeability of the iron because of the flux variation and hence the third harmonic impedance. But small variations affect the permeability only slightly.

Temperature rise of component parts (usually fixed by lifetime requirements) is also limited in this application because of resultant changes in circuit parameters. For example, the capacitor bank is located in a forced air-cooled enclosure. The capacitors are paper insulated and non-inflammable liquid-filled, and generate about 8½ kw in heat energy. As the temperature increases in the enclosure the capacitance of each unit decreases because of its temperature coefficient. A normal amount of this detuning can be tolerated, but continuous operation above the rated energy becomes objectionable.

There is evidence, too, that detuning can result from the slight change in the air gap dimensions of the magnet core that occurs with heating in operation. This effect is negligible under normal operating conditions, but at energies well above the betatron's rating some unbalance will occur.

Electronic circuits

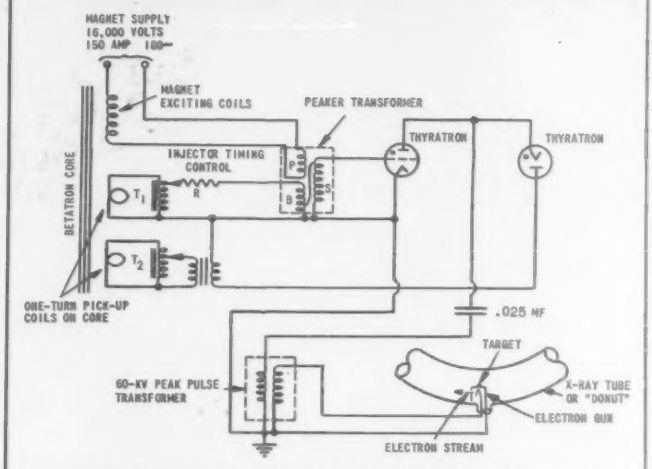
Like the power circuit, the electronic circuits for the betatron have had to be kept as simple as possible for reasons of economy and maintenance. The injector circuit shown in Figure 9 is used to inject the electrons given off by the heated X-ray tube filament at precisely the correct time when the magnetic field is slightly positive and increasing with time. As described in Part I, the electrons are accelerated from this time through a quarter of a cycle when the field strength reaches its peak. Injection and acceleration does not occur again until the next positive cycle.

In the injector circuit, on the alternate half-cycle when electrons are not being injected, the rectifier charges the .025-microfarad capacitor. Within a few microseconds after the start of the next half-cycle, the thyratron discharges this capacitor through a pulse transformer. The high peak voltage from the transformer secondary applied between the filament and plate of the donut accelerate the electrons from the area surrounding the filament into the increasing magnetic field where they are captured and further accelerated by the field.

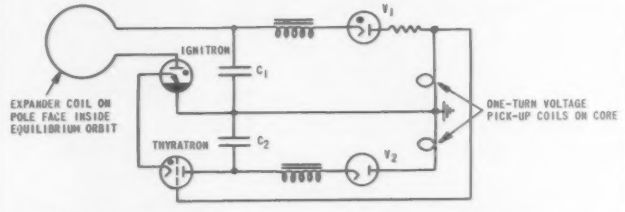
The thyratron is triggered in such a way that the grid-firing time may be varied in the order of a few microseconds for the following reason. Electrons injected at the time the main magnetic field is zero would encounter only the magnetic fields set up by the eddy currents in the poles and core. These fields, occurring at 90 degrees ahead of the main flux and with intensities of about 10-15 gausses at the orbit, are nevertheless strong enough to cause such erratic oscillations of the injected electrons that most of them would strike the conducting walls of the vacuum tube and pass off to ground. The thyratron firing time occurs sufficiently after zero main flux time (when the main field is much stronger than the spurious one). At this time the injection momentum, mv, of the electron and H and R satisfy the equation $mv = \frac{HQR}{c}$, derived in Part I, and a large portion of the electrons can be captured and accelerated around the orbit.

In order to increase the number of electrons captured at injection time another electronic circuit — the orbit contractor — provides a rapidly rising current pulse through a coil of wire on the pole faces at the equilibrium orbit radius. The pulse occurs at injection time and is in a direction to set up a magnetic field opposing the main field. The result of this is that the rate of rise of the main field is increased at injection time, providing larger damping forces to contract oscillating electrons into an equilibrium path.

After injection of the electrons and acceleration to their maximum energy, the electrons are caused to spiral outward from the equilibrium orbit to strike a target. This is accomplished by the expander circuit (shown in Figure 10) at the time when the main betatron flux is a maximum. (With the flux at a peak, $\frac{d\phi}{dt}$ is zero and no additional energy can be gained.)



INJECTOR CIRCUIT is shown above. A pulse of electrons is injected into the donut once each cycle near H = 0 where the electrons are captured by the increasing magnetic field and further accelerated. **(FIGURE 9)**



EXPANDER CIRCUIT of the betatron shown above causes the electron stream to strike the target on the tip of the electron injector after the electrons are accelerated from H = 0 to H = Maximum. **(FIGURE 10)**

In this circuit the rectifiers V_1 and V_2 charge up the capacitors C_1 and C_2 on alternate halves of the cycle. At the proper time the grid on the thyratron goes positive and C_2 discharges through the starting anode of the ignitron. The tube thus started, C_1 discharges sending a pulse of current through the expander coils located on the pole faces just inside the equilibrium orbit. The transient flux established by this pulse causes instability of the main field which promotes large oscillations of electrons around the equilibrium orbit with most electrons striking the target. Expansion conditions are so efficient that about 97 percent of all accelerated electrons strike the target. About 65 percent of the electron's energy is converted into X-radiation and the balance into heat. This compares with an energy conversion of less than 0.1 percent into X-rays for standard 200-kv X-ray equipment.

Since injection and expansion of the electrons occur only once each cycle the X-rays are emitted in pulses — once each cycle for 180 pulses per second.

Both the injector and contractor circuits utilize a peaker transformer to trigger electronic tubes. In this transformer the flux set up by the winding "P" (see Figure 9) is in the same time relation as the main betatron flux since the same current excites both windings. Two windings, "S" and "B," are wound on thin Hypernik strips placed in an air gap in the core (Figure 11). These strips become saturated at low values of primary flux and have a very sharp knee in their saturation curve. The primary flux is sinusoidal in shape but the secondary flux, or that in the peaker strip, is nearly constant in value except for a short interval of time while the primary flux is passing through zero. Thus, the secondary voltage remains very nearly zero except over a narrow interval of time when it rises rapidly to a peaked maximum and, within microseconds later, falls to zero. This may be seen in Figure 11b where instantaneous curves of flux and time are shown.

It is necessary to be able to vary the time this peaked voltage occurs, since the tubes they fire must operate at definite and

the BETATRON in RESEARCH

The potentialities of the highly penetrating radiation from the betatron are being put to use in a number of laboratories in various parts of the world. Many of the most urgent studies under way have to do with the biophysics involved in the interaction of radiation with the human body. This problem actually has two separate but related ramifications.

One is the effect of X-rays, Beta-rays (electron beam) and neutrons on tissue. The other has to do with developing techniques to shield the body from these radiations. To date most of the X-ray and Beta-ray investigations on tissue with energies higher than 2 million volts have been done with the 24-million volt betatron. The effect of the radiation on the hair, skin and organs of rats, guinea pigs and rabbits has been carefully observed so that treatment of cancerous lesions in humans can be controlled with minimum danger to the patient. The negligible effect of induced radioactivity in the bloodstream and tissue due to X-rays was experimentally determined, making possible the safe use of the highly penetrating beam for cancer therapy today.

Learning the best way to shield the body for protection against unwanted radiation is of importance not only to radiologists and X-ray technicians in hospitals and industrial plants but it is of utmost importance in the many centers where atomic research is carried on. Dangerous radiation from high energy machines, from atomic piles and from radioactive isotopes, must be biologically evaluated and adequately controlled.

Another biophysics problem has to do with plant life. Seeds, given controlled amounts of radiation, germinate and grow rapidly. Plants with new characteristics through multiple mutations are developed after several generations have been treated. An understanding of these reactions may open entirely new fields. Sterilization of food products by electron bombardment is another field of application.

In the field of pure physics the betatron offers many possibilities. A large program has been under way for some time in one university investigating the artificial radioactivity that can be induced in metals. Since each substance has a threshold energy for radioactivity it is possible to use this fact in the determination of absorption coefficients or for identification purposes.

By a special arrangement the betatron can be modified to bring the stream of high energy electrons directly out of the donut. Much higher induced radioactivities can be accomplished by immersing the substance in the Beta-ray or electron stream because the high specific ionization of the electrons before coming to rest. Countless other experiments, of course, are possible with the high energy electrons.

precise times with respect to the magnet field. This is accomplished by applying a small voltage (180 degrees out of phase with the magnet voltage) to the bias winding. The current in the bias network is essentially in phase with the voltage from T_1 (see Figure 9), since R is made very large with respect to the inductive reactance of the bias winding. The flux established in the bias winding by the current is thus 180 degrees out of phase with the magnet voltage and lags the magnet flux and the original flux set up in the peaker transformer by 90 degrees. The two fluxes now established in the peaker core add as shown in Figure 11c. The resultant flux wave is actually shifted along the time axis by an amount t_1. The peaked voltage induced in the "S" winding is displaced this same amount from where it originally occurred in Figure 11b.

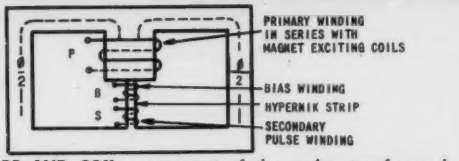
Mechanical design improved over early models

A complete betatron consists of the magnet unit, control cabinet, capacitor rack, and tripler transformers. Since the first commercial 20-million-volt betatron built about six years ago, many advances have been made in construction to reduce maintenance, improve performance and flexibility.

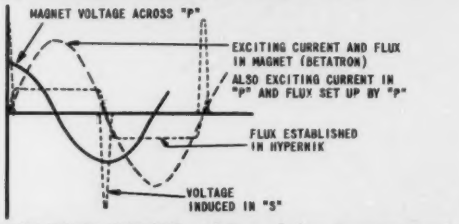
The original units installed (including two used for medical research) have a fixed horizontal X-ray beam, a large combination control panel and capacitor rack, and several other features which, although they are satisfactory for industrial radiography, do not lend themselves well to medical use. Development of new units with a high degree of flexibility that meets cancer therapy requirements and has improved utility for industrial radiography has been going on for the past year and a half. The first unit of one of the new design has been installed in the betatron laboratory and others are under construction. Figure 12 shows this new model.

In this new design, the magnet core weighs approximately 4½ tons and is suspended by pedestal-mounted bearings. A 2½-inch shaft connects the core with a motor-driven gear reducer so that the entire core (and hence the X-ray beam) can be moved through an angle from 40 degrees above the horizontal to 40 degres past a downward vertical line. The suspension was designed so that the tremendous forces on the pedestal in any direction will not move the core more than .002 inches.

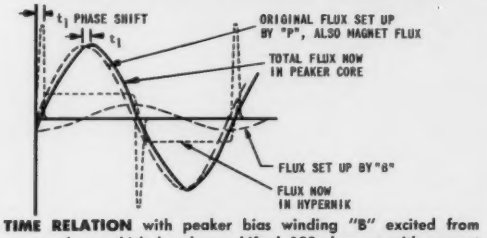
Previous mention has been made of the magnetic fields set up by the eddy currents in the poles and yokes of the magnet.



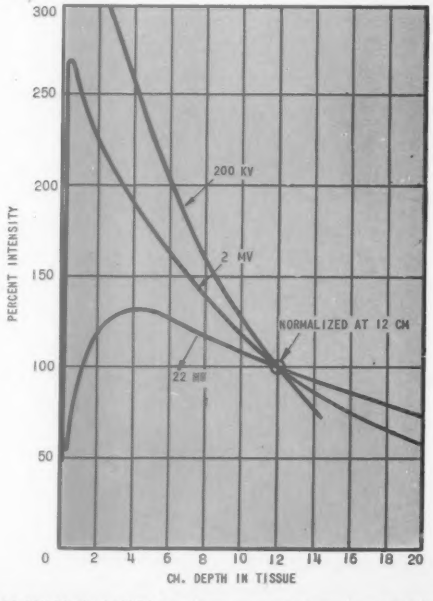
CORE AND COIL arrangement of the peaker transformer is shown above. High voltage pulse generated in the "S" winding triggers the electron injector circuit. **(FIGURE 11a)**


MAGNET VOLTAGE ACROSS "P"
EXCITING CURRENT AND FLUX IN MAGNET (BETATRON)
ALSO EXCITING CURRENT IN "P" AND FLUX SET UP BY "P"
FLUX ESTABLISHED IN HYPERNIK
VOLTAGE INDUCED IN "S"

TIME-VOLTAGE CURRENT and flux relations in magnet core and peaker transformer without excitation on bias winding "S" is illustrated by curves shown above. **(FIGURE 11b)**


t_1 PHASE SHIFT
t_1
ORIGINAL FLUX SET UP BY "P", ALSO MAGNET FLUX
TOTAL FLUX NOW IN PEAKER CORE
FLUX SET UP BY "S"
FLUX NOW IN HYPERNIK

TIME RELATION with peaker bias winding "B" excited from source phase which has been shifted 180 degrees with respect to magnet excitation phase is plotted above. **(FIGURE 11c)**



24-MILLION VOLTS for deep cancer therapy has minimized skin reaction and nausea. Surface dose is extremely low and the absorbed dose in intervening good tissue is much less than that for lower voltages. **(FIGURE C)**

the BETATRON in CANCER THERAPY

Higher energies than those available from radium or conventional X-ray machines have been sought for years by radiologists doing work in cancer therapy. The advent of the betatron has offered hope of healing to many cancer victims whose cases were previously beyond the range of known methods of treatment.

With conventional X-ray equipment the greatest obstacle to the delivery of a destructive dose of X-radiation to a deep-seated tumor is that the skin and intervening tissues may suffer great damage in the process. Most of the equipment used by radiologists for deep therapy is in the range of 200 to 400 kv. A few installations have X-ray generators of one to two million volts.

Up to energies of less than one-million volts the skin dose is always higher than the tumor dose. As voltages are increased above two-million volts the dose delivered to the skin is actually less than that delivered to the tumor. For example, at 24-million volts the amount of ionization that takes place four centimeters below the skin is many times the amount that occurs at the skin surface. The significance of this is that the skin becomes relatively unimportant as a limitation on the amount of radiation that can be delivered to a tumor.

The advantage of an X-ray machine with which the maxi-

It is important that these be kept to a minimum. In order to do this, high quality transformer steel is used and deburred after shearing with greater care than is necessary for ordinary transformers. After varnishing, the laminations are laid up carefully in an extremely accurate stacking fixture to form the yoke sections. Any scratches accidentally made across the edge of a stack usually means that the core must be stripped down to the damaged areas and rebuilt. Fishpaper insulating sheets are inserted at intervals in the yoke to aid in cutting down eddy currents. Since various parts of the core are spaced apart from themselves and from the poles by thin fishpaper shims to help establish the proper field shape for the equilibrium orbit, core stacking tolerances must be held to .005 inches on the several butt joints. This is not easy even with an accurate stacking fixture because laminations are slightly wavy and tend to "walk" when clamping bolts are tightened. Redesign of laminations, ventilating grids, and improved clamping techniques has overcome this problem partially.

Since the flux density in the poles is high, they are made of highest grade oriented transformer steel laminations laid up radially in a patented assembly. The laminations are spot-welded together into the sectors and then the sectors welded with a special welding rod at the center. Insulating papers are used between each bundle of laminations. The stacking fixture used for this purpose is designed such that no metal comes in contact with the lamination edges while the pole is assembled.

Over a period of time eddy currents gradually increase as a function of temperature rise and vibration. Insulation life is approximately halved with every eight degree C increase in temperature, and since 360-cycle vibration is present to loosen the disintegrating insulation particles lifetime is again adversely affected. For this reason the recently designed units incorporate greatly improved cooling and reduced vibration to increase life expectancy of the unit appreciably.

24-MV BETATRON shown above is constructed to permit angular rotation of the X-ray beam in a vertical plane. Other models permit much greater degrees of freedom for the beam providing greater utility. **(FIGURE 12)**

The control panel and capacitor rack are separated in the new models. Two types of control cabinets are available. One is of the console type, the size of an office desk. It has an enclosed panel along the rear for instruments, signal lights, and controls. An indicator is used to provide remote indication of the orientation of the X-ray beam. The left side of the desk contains a sliding rack on which electronic equipment is mounted. Other control devices are mounted in the trunnion pedestals of the magnet unit. The second type of cabinet is a vertical control cabinet similar to those already in use with conventional X-ray machines.

As a separate unit, the capacitor rack is located in the transformer room with the triplers. It contains all the capacitors necessary to tune the inductance of the magnet unit and the triplers. Resistors to vary the magnet energy from lower energies to 25-million volts are installed in a separate enclosure.

mum dose can be made to occur several centimeters below the surface is best illustrated by Figure C. In this set of curves an arbitrary tumor location is taken at some body depth. For purposes of comparison, the tumor dose is made 100 percent for all cases. Notice that at 24 million volts the maximum dose is only 32 percent greater than the tumor dose at 12 centimeters.

The lower energies yield a much, much higher overlying dose, leading to extensive damage of healthy tissue before a useful tumor dose can be obtained. Where the skin dose is high, severe burning will occur and, because of the large amount of X-radiation absorbed by the intervening healthy tissue, nausea (radiation sickness) invariably results. Although skin damage may be negligible at two-million volts, the overlying dose is still too high for satisfactory therapy in many instances. The answer is not to reduce the tumor dose so that tolerance levels in the overlying tissues may be met, because to be effective the tumor dose must be no less than a predetermined amount. In an effort to overcome the harmful effects discussed above, the radiologist has been forced to apply the X-ray beam at many entrances (crossfiring), keeping the overlying dosage as low as possible and thus adding to the dose at the tumor.

With the 24-million-volt betatron, the overlying tissue dose is so close to the tumor dose that the opportunity for skin reaction and nausea is practically non-existent with only two or more crossfirings. In addition, there are other less obvious advantages that make the betatron a more efficient machine for deep therapy, such as the independence of field area on dose and the uniform distribution of dose over the treatment area. The net result is full treatment without discomfort, fewer treatments for a given case, and the possibility of treatment at some bodily locations impossible with low voltage machines.

It appears impractical to go to much higher voltages in the treatment of cancer for several reasons. First, at higher energies the exit dose becomes higher and will limit the tumor dose as much as the high entrance dose does now on low voltage machines. Secondly, the Roentgen ray beam becomes progressively narrower as energy increases, making it necessary to use exceedingly long focal-skin distances for the same treatment area. The disadvantage here is that the treatment time would increase, since it varies inversely with the square of the distance between the tumor and the X-ray target.

At present the 24-million-volt betatrons are in use at two hospitals treating cancer. Several other hospitals are designing new treatment rooms to house 24-million-volt betatrons for delivery as soon as building construction can be completed. Results to date have proven very encouraging and interest has been aroused throughout the world in the great hope the unit holds for cancer victims.

11 YEARS on the Line

✓ No Maintenance
✓ No Downtime

THIS ROCKING CONTACT VOLTAGE REGULATOR has been on the line without downtime or maintenance since installed eleven years ago!" says Mr. Kudick, engineer-in-charge of the East Wells Street Power Station of the Wisconsin Power Company in Milwaukee. "This regulator was installed to hold down voltage peaks . . . it does the job. Performance has been excellent."

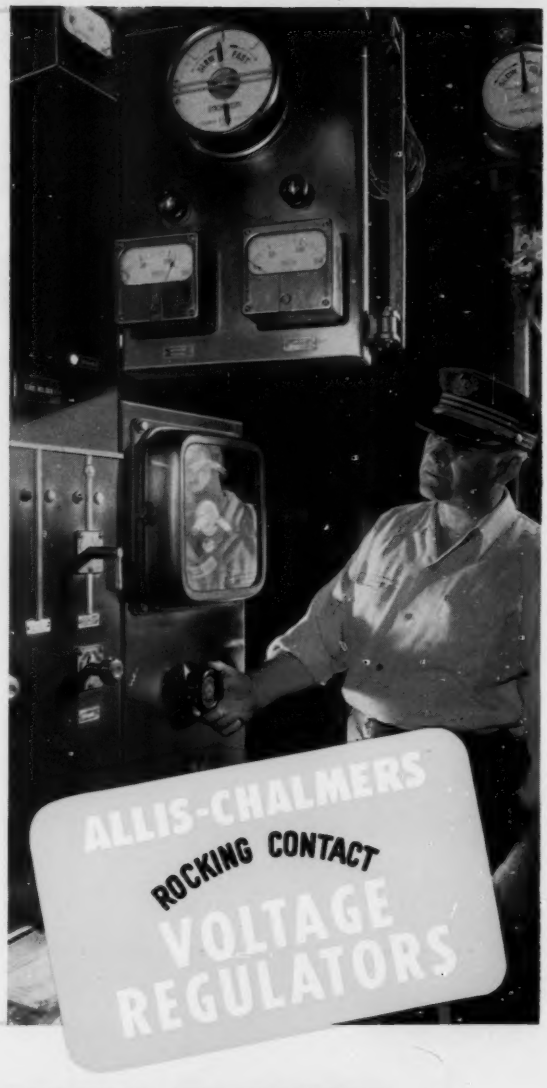
What are reasons behind this typical performance?

1. Allis-Chalmers Rocking Contact Generator Voltage Regulators have no vibrating contacts, no gliding friction, no complex adjustments. The few moving parts are all supported in jeweled bearings.
2. They are genuinely precision manufactured. Sectors rock on accurately machined commutator segments that are silver surfaced for positive contact, long life.

If you want long years of trouble-free service, specify *Rocking Contact* Generator Voltage Regulators for your next switchgear or switchboard . . . or replace inefficient regulation now! Call your nearby Allis-Chalmers representative or write direct for more information.

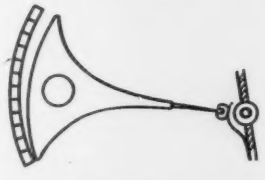
A-3148

Allis-Chalmers, 848-A S. 70th St.
Milwaukee, Wisconsin

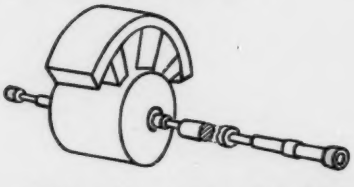


WHY POWER ENGINEERS IN UTILITIES AND INDUSTRY PREFER ALLIS-CHALMERS ROCKING CONTACT REGULATORS:

Each commutator segment is connected to a wire wound resistance element that is accurately designed according to the characteristics of *your* generating equipment. Resistance elements are air cooled —commutator is in dust-tight enclosure.



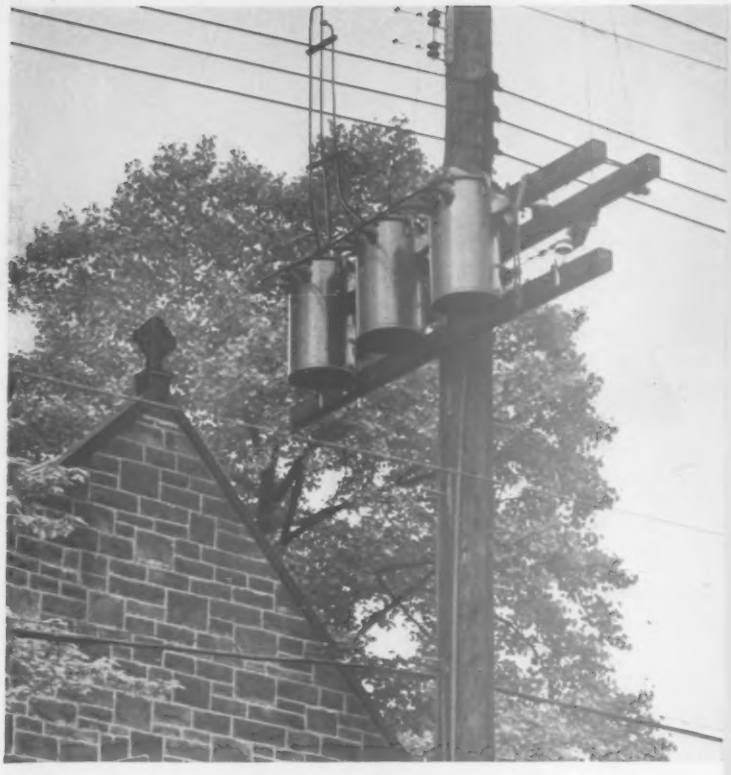
Rocking Contact sector pivots on jeweled bearing . . . has smooth working, hard graphite face that rocks on curved, silver surfaced commutator . . . regulates with slight movement . . . reduces wear . . . maintains accuracy.



Quick acting torque motor drives Rocking Contact Sector . . . has jeweled bearings for rapid, accurate, anti-friction movement. Aluminum rotor reduces inertia . . . increases speed of response.

ALLIS-CHALMERS

T. H. BLOODWORTH
CONTROL
M. O. ANNEX



A 1000 kva power transformer ready to receive sound level tests in Allis-Chalmers Pittsburgh Works sound laboratory. Laboratory walls of concrete, glass wool and acoustical tile exclude 99.98% of exterior noise power.

Here a distribution transformer is getting sound and harmonic analysis. Physical noise level and harmonic index are new tools to measure sound energy. Transformer designs, in addition, are tested in accordance with ASA and NEMA standards.

Quiet Neighborhoods

NEED QUIET TRANSFORMERS

How to Beat Transformer Noise—That's The Problem Allis-Chalmers Engineers Are Tackling In Their Pittsburgh Sound Laboratory

TODAY'S DEMAND FOR quieter transformers is stronger than ever before. Larger rated transformers are moving into residential areas as distribution systems grow up. That's why holding customer good will depends more and more on keeping transformer sound level low.

What is Allis-Chalmers doing about sound level? In cooperation with sound experts, Allis-Chalmers engineers are conducting research on new electrical core steels in an effort to reduce magneto-striction and resonance. They're testing effects of clamping pressures, core impregnation and anchoring of core and coil assembly. Their laboratory is specially equipped for sound level experiments.

What will be the result? Transformers that create good will. Research, engineering and production are teaming up at Allis-Chalmers to give you a transformer that is truly a good neighbor.

For details on Allis-Chalmers transformers contact your nearby A-C sales office or write for bulletins:

Bulletin 61B7309A — *ACP* (Allis-Chalmers self-protected) distribution transformers.

Bulletin 01B6168B — Complete A-C power and distribution line.

Bulletin 61B6014A — Substation transformers, 50 to 500 kva.

A-3170

**Allis-Chalmers, 848-A S. 70th St.
Milwaukee, Wisconsin**

ACP (Allis-Chalmers Protected) is an Allis-Chalmers trademark.

ALLIS-CHALMERS